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Tree Defects: A Photo Guide

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Dr. Shigo has used a chainsaw to make longitudinal dissections of thousands of trees. He has studied trees throughout the United States, and in Canada, Australia, Europe, and Asia in his research on the response of trees to injury and infection. He has packaged parts of his research findings to reach many audiences worldwide.

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Abstract

Dissections and wounding studies on thousands of trees since 1959 have resulted in an expanded concept of tree decay. A long gradation of events begins after wounding as tree and microorganisms interact. The highly compartmented tree forms boundaries to resist the spread of microorganisms. This defense process is compartmentalization, and CODIT is a model of the process.

The expanded concept of decay and CODIT are used to reexamine many tree problems. Discolored and decayed wood are major tree problems that cause low quality in trees. A better understanding of these defects makes it possible to begin growing healthier and higher quality trees in our forests and cities.

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The guide gives an historical pictorial overview of the development of the CODIT model. CODIT is a model of Compartmentalization Of Decay In Trees. CODIT shows how trees are built up in highly ordered compartments. Trees survive after injury and infection so long as they recognize and compartmentalize the injured tissues, confining them to small volumes rapidly and effectively. When trees break down from disease or decay, they do so compartment by compartment.

Field dissections that led to the CODIT model are shown first. The application of the model to many other tree problems is then shown. A constant thread that runs through the photos is that many problems in wood products have their origin in the living tree.

1. Thousands of trees with wounds were dissected longitudinally. The decay did not spread outward into new wood formed after wounding, as this American beech shows.

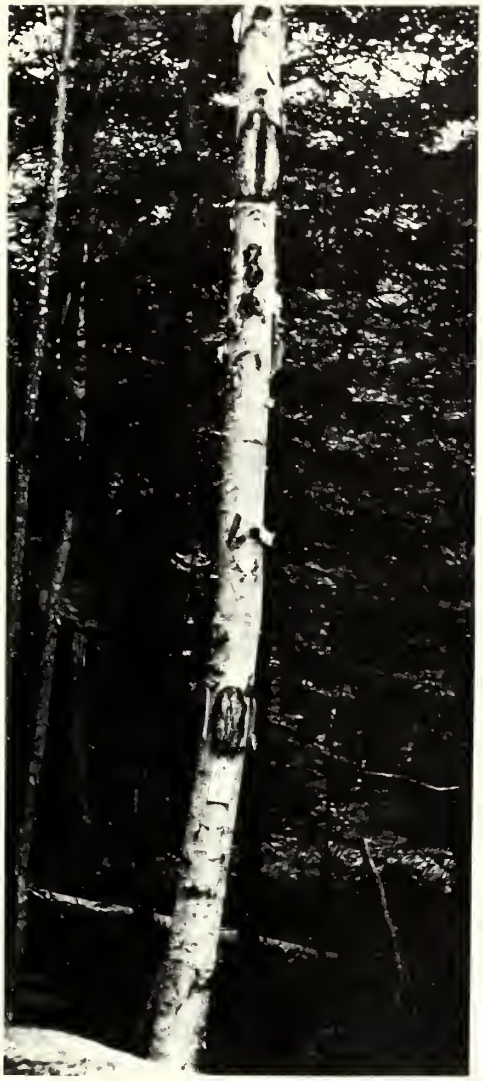
2. And this beech with decay associated with *Fomes igniarius*.

3. Cross-sections of trees showed the same patterns: the decay was confined to the wood present at the time of wounding, as in this yellow birch.

4. New questions arose as more trees were dissected. Dissection of this paper birch showed that the central column of colored wood was associated with the wounds.

   Most birch trees did have a central core of colored wood, but some trees, even large, old trees, had no colored cores. The discolored wood was associated with wounds.

   Dissections showed that some columns of discolored wood associated with the wounds were very small, while others were large. Wound size and depth were important factors affecting size of internal columns of discolored and decayed wood.



5. The wound on this yellow birch was 50 years old. The large arrows show the size of the discolored core at the time of the large wound. The small arrows show the size of the tree at the time of wounding. The decay did not spread inward into the wood that had been altered by previous wounds, or outward into the new wood that formed after wounding.

6. Patterns were complex in sugar maple, but more dissections revealed their high order. This tree had an old basal wound—over 75 years old. The fruit body was *Fomes connatus*. The large wound above was inflicted by sugar maple borers, *Glycobius speciosus*. The type of decay associated with each wound was different, but the fungi were confined to the wood present at the time of wounding, even after more than 75 years.

7. More and more sugar maple trees with clear wood to the pith were found. The 8-year-old basal wound caused very little defect. A dark line was often seen in the growth ring that formed after wounding (arrow). The question of whether beech, birch, and maple have a normal central core of colored heartwood began to emerge.

8. The dark line (arrow), was first called "barrier cells". The cells formed after wounding, and they separated the infected wood from the sound wood. *Barrier zone* was the term given later to these cells. The barrier zone was easy to see in sugar maple. The pattern of discolored wood forming first, and then decayed wood spreading within the discolored wood, and the pattern of bacteria, non-decay-causing fungi, and decay-causing fungi all began to take shape.

97

2
SM

9. Dissections of American ash showed the same internal patterns as the other species of hardwoods. Note the light colored central column (small arrows). This was associated with many small stubs. The large arrow shows a barrier zone.

10. Dissections began to focus on branch stubs. Decayed wood associated with large old stubs was confined to the wood present at the time the branch died. Note that the discolored wood associated with the stub on this paper birch does not spread into the central column of discolored wood associated with older branch stubs.

11. This large old stub on a paper birch was "pinched off". The decayed wood is strongly walled off within the old internal branch wood. The decay did not spread outward into the healthy wood.

12. The hollow branch base in this yellow birch was surrounded by a light-colored column of decayed wood. The central column of decayed wood was associated with many branch stubs. Each new column of decayed wood remains separate from the others. This pattern would be impossible to understand from cross sections.

13. The dead spot below this small stub on a red maple indicates that the cambium was injured when the branch tore away from the main stem. The discolored wood was walled off within the wood present at the time the branch died.

14. Two major leaders died on this yellow birch, and the third leader grew to be the main stem. Note how neatly the leaders are walled off from each other. The decayed socket in stub A was essential for effective shedding. A similar socket of decayed wood is in stub B. The upward extension of discolored wood associated with stub A indicates that the trunk was injured when stub A fell away from the trunk.

15. Two large old branch cores on red maple. Note the tip of decayed wood in the lower branch core. Decayed wood is essential to shedding. The decayed wood extended farther into the inner branch wood in the upper branch. The central core of discolored wood in beech, birch, maple, ash, and many other trees is associated with the death of branches and the alteration (and usually infection) of the wood present at the time the branch died.

A
B

16. Dissection of this sugar maple shows a clear base, but discolored wood associated with branch stubs. The discolored wood in the trees studied yielded many species of bacteria and fungi, usually species in the genus *Phialophora* and closely related genera. The results began to show a succession of microorganisms associated with discolored and decayed wood.

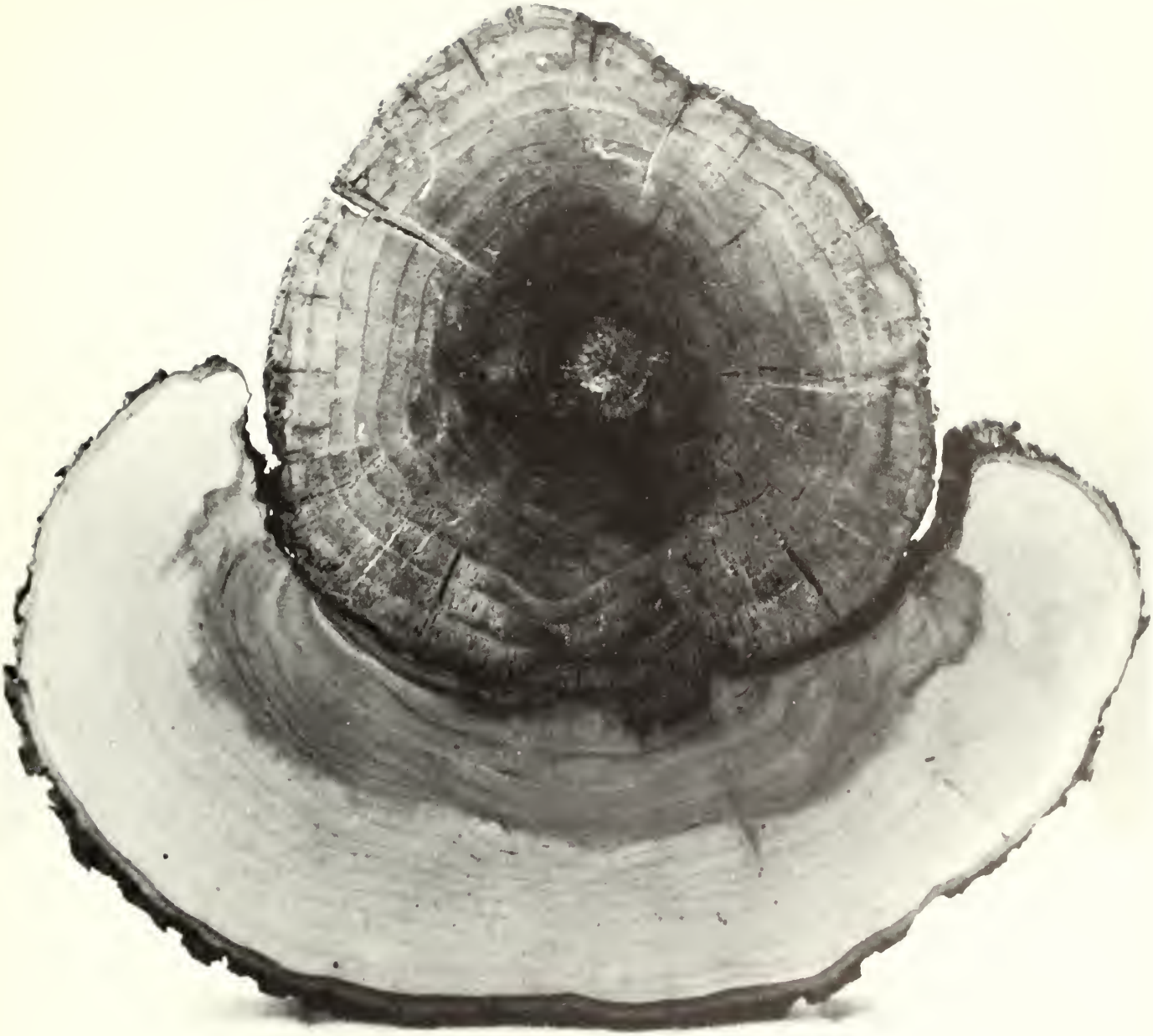
17. Dissection of very small stems showed patterns similar to those of large branches and similar microorganisms were isolated from the discolored wood. The small inner branch cores were walled off. It appeared also that there was a blocking of the pith connection between branches and main stem.

18. Dissections of branch stubs on oaks and other heartwood-forming trees showed patterns similar to those in birch and maple. The discolored wood associated with the dead branch on this red oak was walled off within the wood present at the time the branch died. The discolored wood was discolored heartwood (arrows). Heartwood will wall off defects, and heartwood will discolor. If heartwood is an unresponsive tissue, how can this be?

19. It was time to begin rethinking our beliefs about heartwood. The classical concept of tree decay, the heartrot concept, would have you believe that once heartwood was infected, the fungi would grow at will into a hollow formed by complete digestion of heartwood. It was time to question this concept.

20. Dissection of white pines showed that the diameter of hollows was the diameter of the tree when it was wounded. Sound heartwood surrounded the hollow. How could this be so if the classical heartrot concept were true?

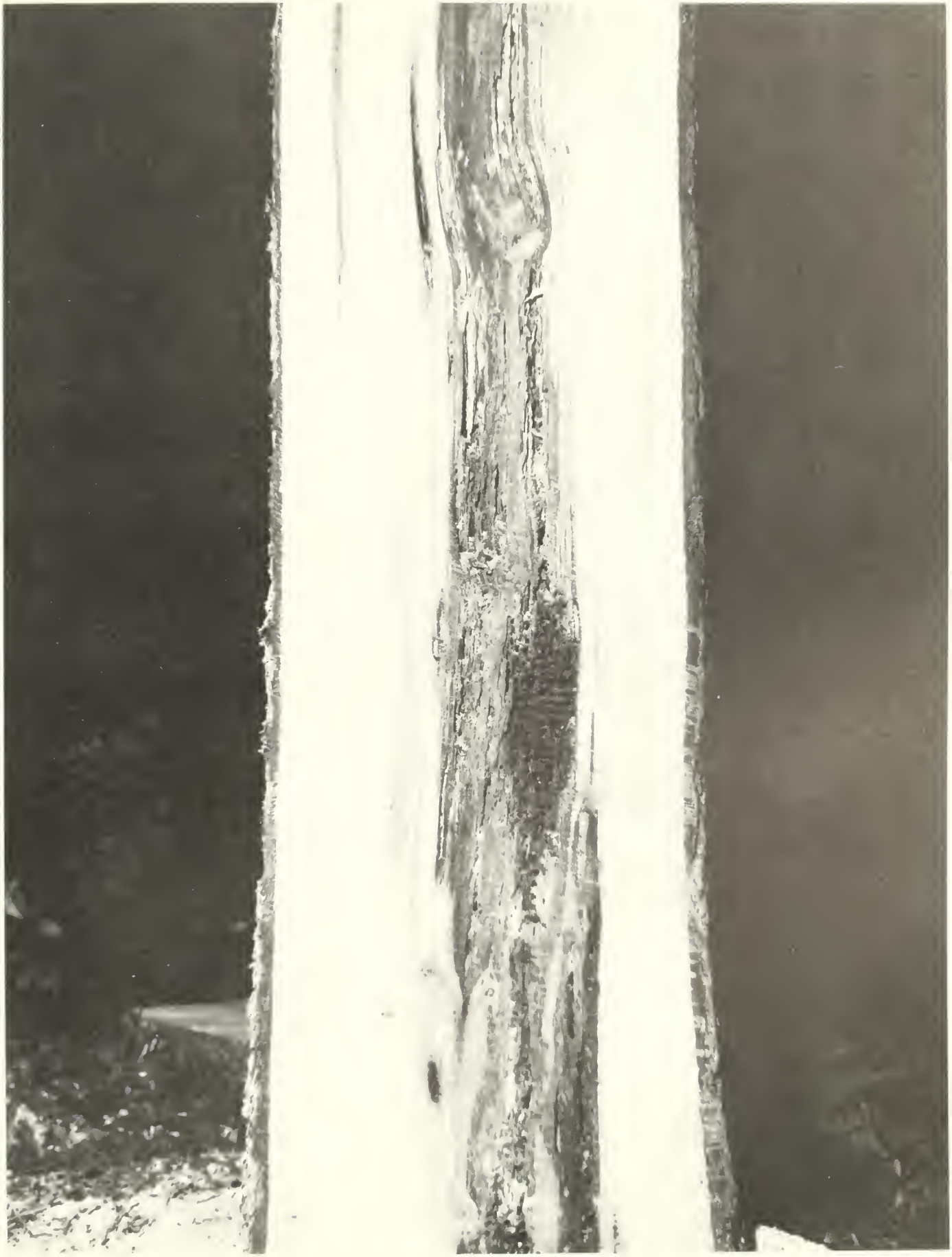
21. Dissections of tree species that have a normal heartwood showed patterns similar to those in birch and maple. The decayed wood in this black cherry did not develop into the surrounding heartwood, even after 20 years. Where small radial cracks formed, the decayed wood did move out, but still only very slightly. It appeared that the heartwood-forming trees also had similar patterns of discolored and decayed wood, even within heartwood.



22. Similar patterns were seen in other heartwood-forming trees such as this black locust. The diameter of the hollow was the diameter of the tree at the time of injury. Even after almost 40 years, the so-called "heartwood rotting fungi" did not spread outward into the heartwood that surrounded the hollow. These observations suggested that microorganisms could only infect wood that was first altered by injury.

23. Longitudinal dissections of red oaks strenghthened the developing hypothesis that heartwood does wall off or confine discolored and decayed wood. And even further, that insects such as ants that infest trees also stay within the tissues present at the time of injury (arrow). Microorganisms and wound-infesting insects apparently do not move "at will" in a tree.

24. Ants infested the column of discolored heartwood in this white pine. The discolored heartwood is surrounded by about 75 growth rings of sound wood. Dissections of oaks, cherries, pines, walnuts, and other heartwood-forming trees began to show more clearly that a fundamental survival process may be operating. And, it was highly ordered.



25. Trees were dissected to determine patterns of discolored and decayed wood associated with old dead leaders, or old main stems that had died. A lower branch then began to grow as a new leader. The old leader stub was called a stem stub. The trees that had stem stubs acquired a characteristic curve.

The diameter of the old leader at the time it died was the diameter of the column of discolored and decayed wood, and the column developed mostly downward. Some discolored wood developed upward in the new leader when the branch was large and had a close connection with the old leader. The diameter of the discolored wood in the new leader would be the diameter of the branch at the time the old leader died.

26. The old leader decayed completely on this yellow birch. Discolored wood in the new leader was associated with branch stubs higher in the stem. The decayed wood did not spread outward to the surrounding discolored wood on the inner side, or to the clear wood on the outer side. These observations led to questions about whether it was wise to break the hard rim or barrier zone when cavities are filled in trees.

27. Dissection of beech shows a connection of the decay column from the sprout with the main stem. Note that the decay does not move outward (large arrow). The sprout has been dead for approximately 50 years. Approximately 50 growth rings separate the decay in the trunk from the bark (small arrow).

28. A low sprout on a sugar maple. The sprout did not connect with the main stem aboveground, hence the sprout decay is separated from the main stem.

29. Dissections of many large, old red maple sprout clumps showed that decay did not spread from the old parent stump to the sprout stems. Decay did spread from sprout stubs at the base of still-living sprouts. Most of the defects in the sprout stems were associated with old branch stubs. Fungi that cause canker rots, such at *Polyporus glomeratus* (arrow), were associated with the stubs. When a sprout stem is cut, and decay develops in the cut stub, the decay may spread to the still living sprout attached to the stub. The greatest diameter of decay in the still living sprout will be its diameter at the time the connecting sprouts are cut. For example, if a 2 inch diameter sprout is cut from an attached 3 inch diameter sprout, decay could develop later into the 3 inch core of the still-living stem.

30. Old decaying parent stumps of red oak were dug out and dissected to reveal the attachment of the sprouts. Decay from the stump did not spread into the sprouts. The heartwood attenuated as it developed downward. There was no heartwood in roots. Dissections of many oaks showed that what appeared as a single stem was really the coalescence of several sprouts.

31. As more trees were dissected, the important role of insects and other wounding agents became obvious. Insects infested this yellow birch after it was wounded. At the 4-foot position (section at right), the decay associated with the wound spread inward to meet the already present circular column of discolored wood. At 16 feet above the wound (section at left), the patterns of insect infestation were still obvious. The central column was very small at this height. Note also the slightly darker shade of the wood present at the time of wounding. This wood is slightly pink in birch and maple. No matter how such wood is dried, it will be a darker shade than the wood that continues to form after wounding.

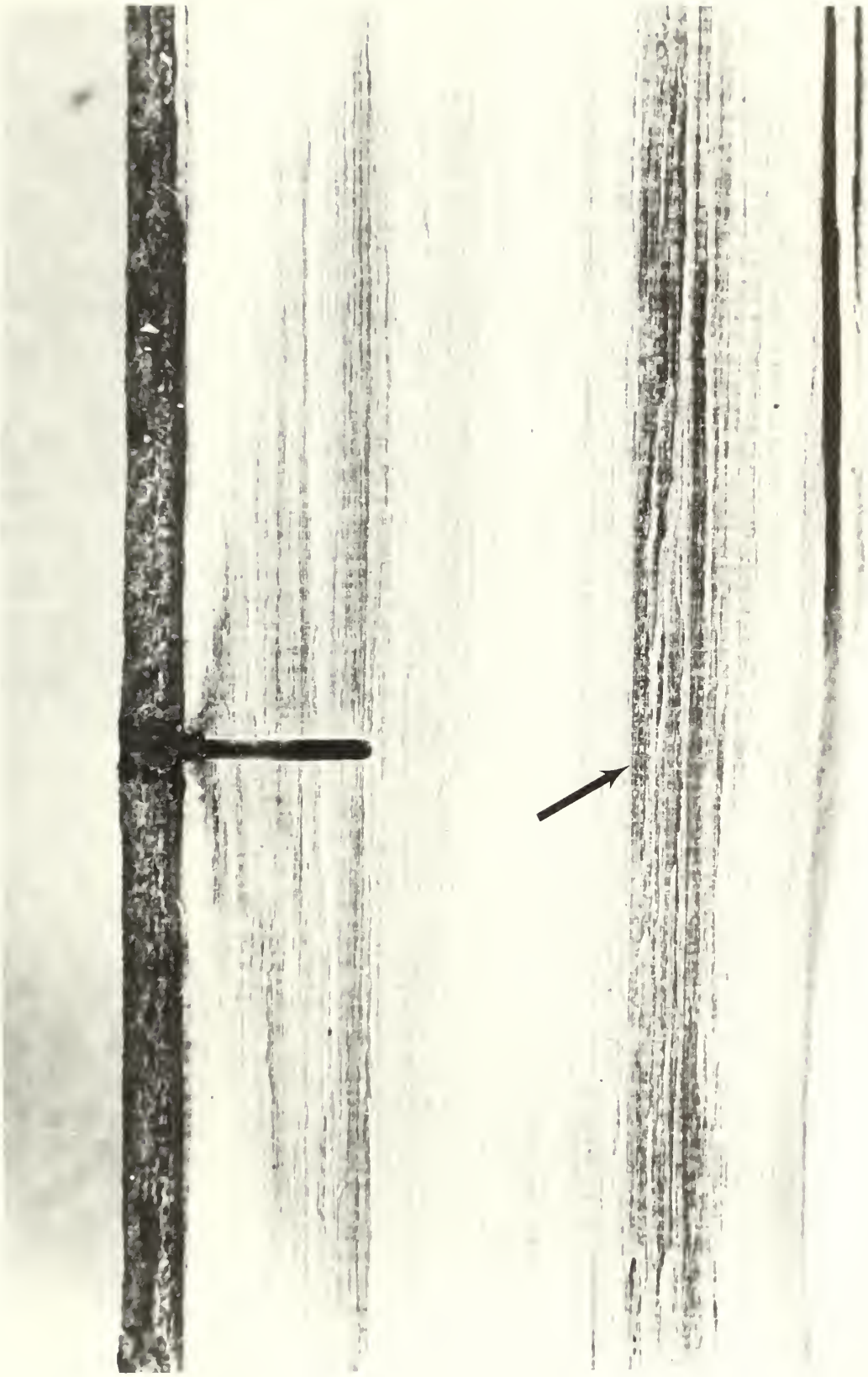
32. The sugar maple borer is a major cause of damage to sugar maple. The beetle has a 2-year life cycle. The discolored wood associated with the beetle wounds often has margins of dark green to orange. The discolored streaks are often called mineral streaks. "Mineral streaks" are columns of discolored wood associated with wounds. In sugar maple, the major wounds that initiate so-called mineral streaks are caused by the sugar maple borer, squirrels, and yellow-bellied sapsuckers. Often these wounding agents occur in clusters.

6Y

16
4
6Y

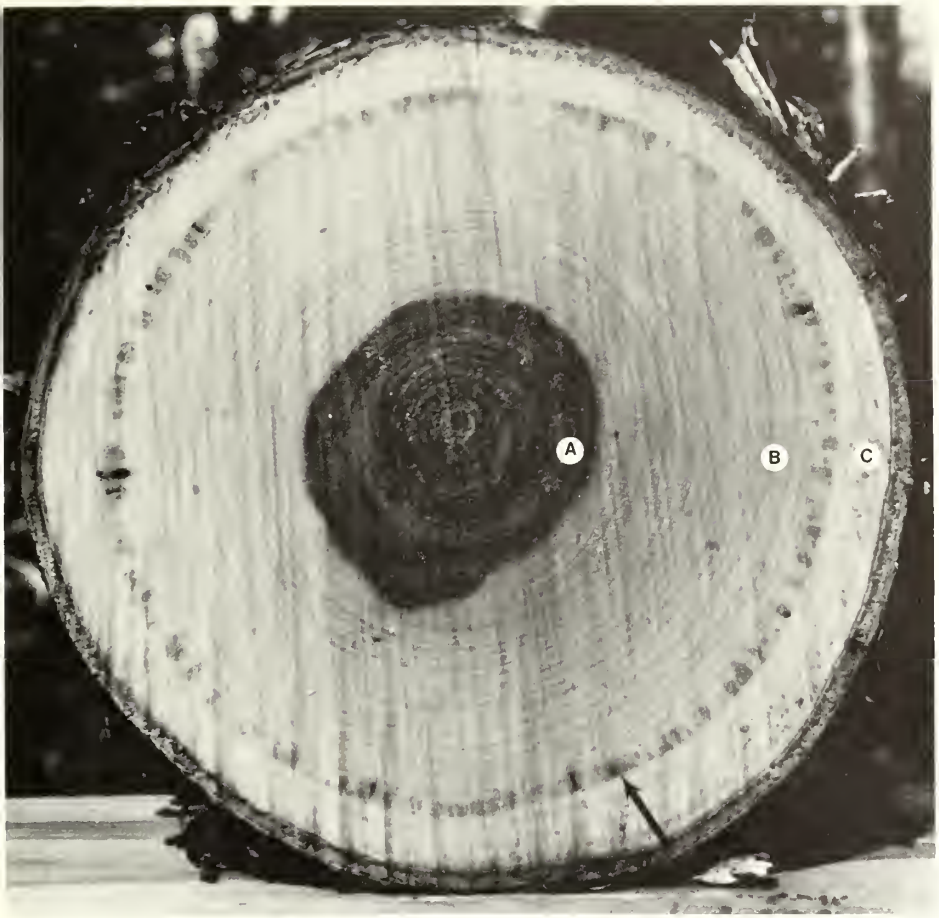
Borer
Damage

33. Small ambrosia beetles often bore into trees weakened or stressed by other agents. The small drill-like bore hole in this red maple was caused by an ambrosia beetle. Discolored wood formed above and below the hole. Also in this sample are vessel plugs that form in discolored wood (arrow). The plugs look like small patches of cotton in the vessels.



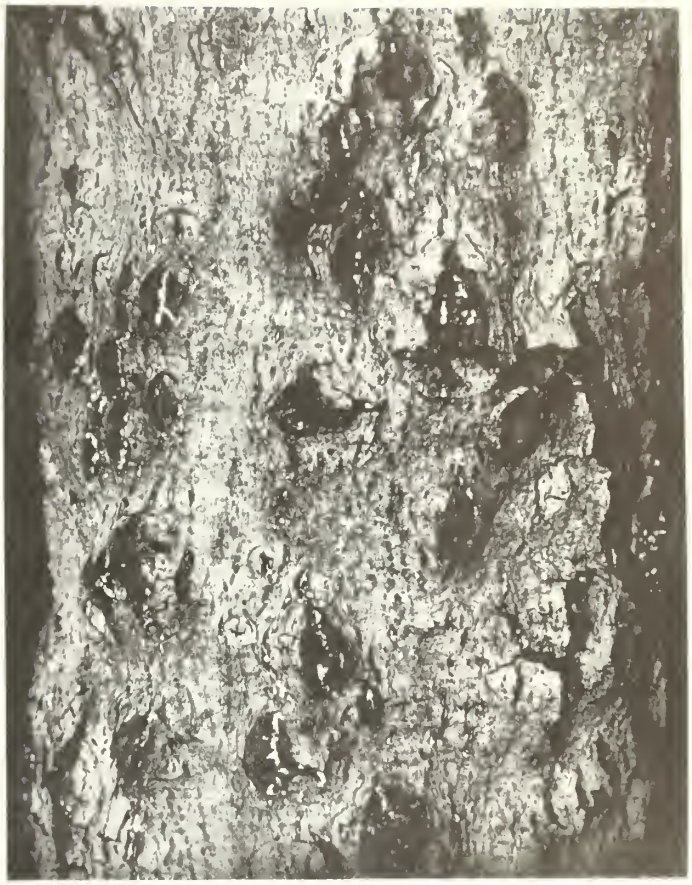
34. This paper birch was attacked by many ambrosia beetles 4 years before it was cut. Note the many small drill-type holes around the trunk (arrow). The central column of discolored wood is called red heart (A). Bacteria and non-decay-causing fungi abound in red heart wood. The wood on the inner side of the insect attack zone was a light shade of pink (B). The wood that formed after the insect attack was bright (C).

35. Cambium miner, an Agromizid or type of fly, in paper birch. The larvae mine downward in the developing wood, and they leave their tracks as a thin dark line. The arrow shows a circle of darker pink wood associated with another wound.


A
B
C

36. Yellow-bellied sapsucker wounds on a Canadian or Eastern hemlock. The wood often separates along the growth ring that has the wounds. Such ring separations are called ring shakes. The ring shakes form only where many peck holes are inflicted, and after at least 15 to 20 years.

37. Another scale insect on beech, *Xylococculus betulae* causes a bark roughening. The scale often becomes established at the base of weak and dying branches. The branch collar is killed, and when the branch is shed, a sunken area remains (left). The roughened bark may also serve to harbor low populations of the beech scale, *Cryptococcus fagisuga* (upper right). The tree walls off the injured areas, but included dead bark may persist as a defect (lower right). Some beech trees are highly resistant to the beech scale, and the Nectria fungi, and even to *X. betulae*.



38. Canker-causing diseases are common on trees, especially on weakened or stressed trees. Swollen dead spots, or cankers, (left) are common on young and old maples. The canker-causing fungi seldom invade far above or below the canker (right). The discolored wood is very hard and heavy and often resists decomposition. Nectria fungi are commonly associated with such cankers. The cankers remain perennial as the fungus reinfects the bark, and a small amount of additional cambium is killed. After the cambium is killed, the tree responds by walling off the infected tissue, hence the circles or bands which give some cankers a target shape.

39. Walled-off Nectria canker on beech.

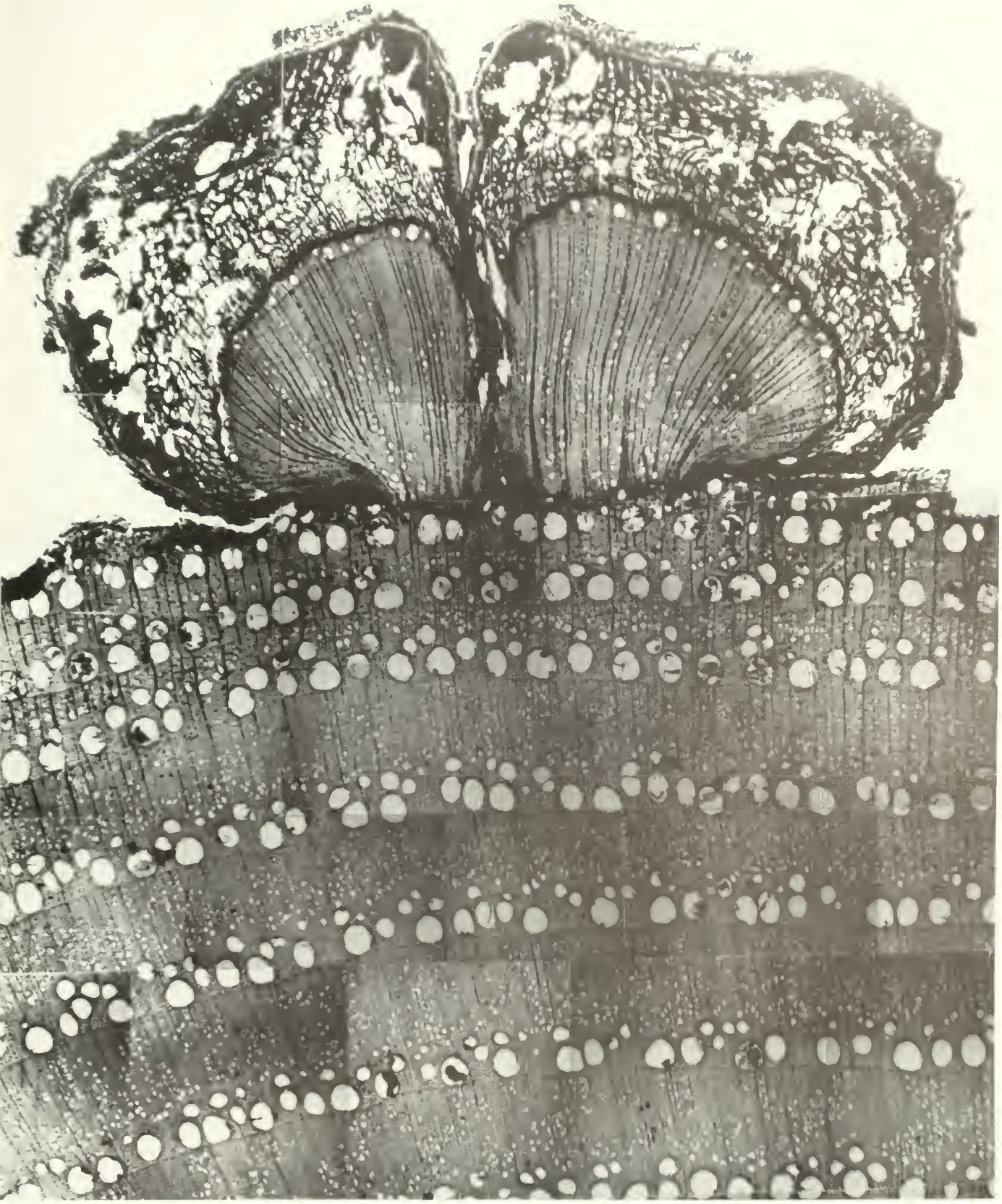
40. *Fomes igniarius* is a fungus that causes canker rots like those shown here on beech. The arrow shows the hard mass of fungus tissue that pushes into the bark as a wedge. When the wedge spreads in the bark, a seesaw action begins: some cambium is killed, and the tree responds to wall off the "enlarged wound". This action is repeated over the years. Some canker rot fungi such as *F. igniarius*, produce fruit bodies with spores. Other fungi, such as *Poria obliqua* (*Inonotus obliquus*) produce very large masses of fungus material, but no fruit bodies on the living tree.

41. The canker rot fungi produce hard wedges of fungus material out into the bark (arrows). The wedges "fan out" in all directions from the center of the canker. When they protrude more deeply above and below the canker, an elongated spindle-shaped canker results. When the wedges spread evenly into the bark around the center canker, a round, knob-like canker forms. Such round, swollen knob-like cankers are commonly associated with *Polyporus glomeratus*, as is the canker shown here.

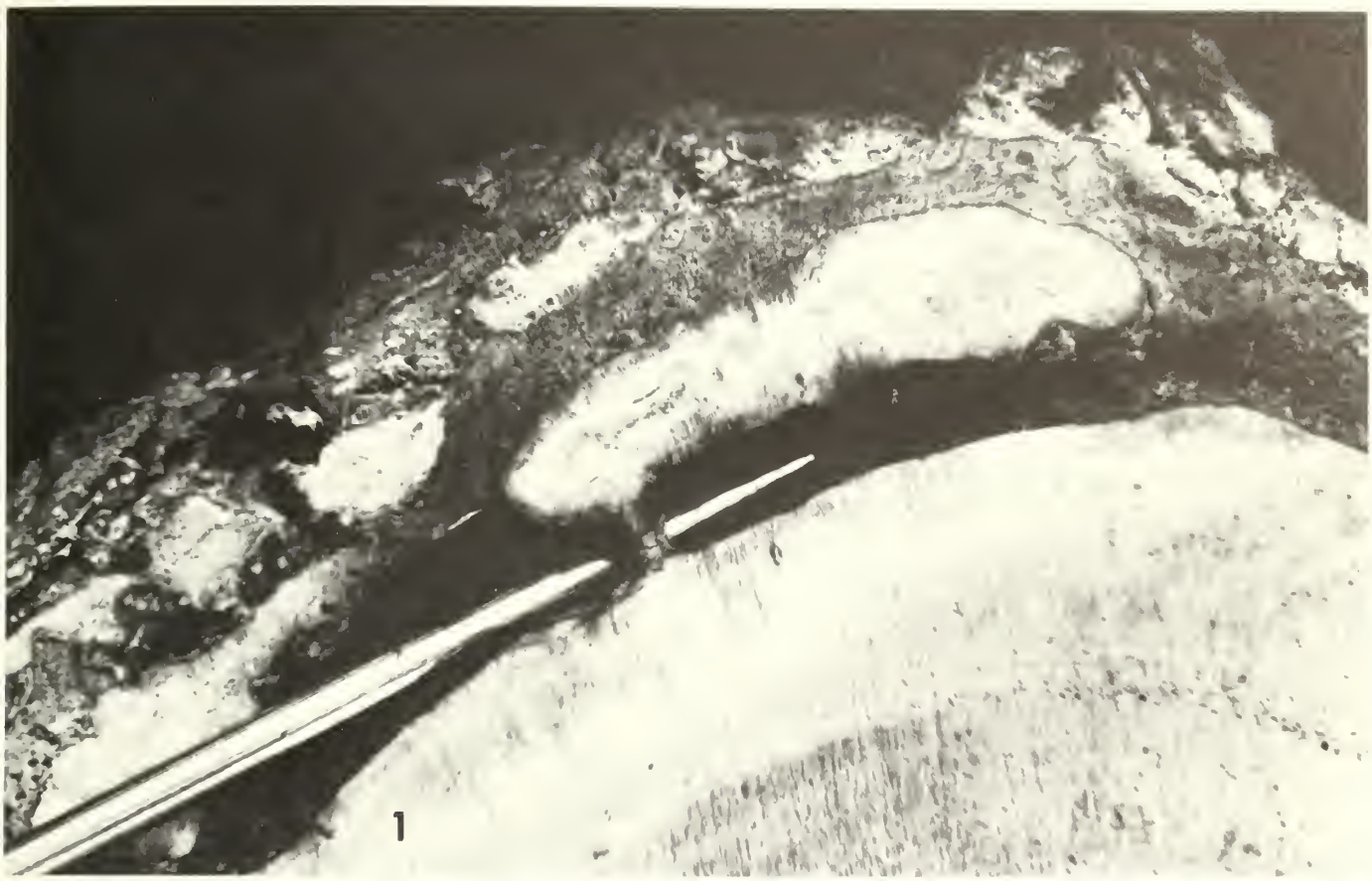
42. A deep fungus wedge of *Poria obliqua* (*Inonotus obliquus*) on paper birch. Note the boundary tissue separating the wedge from healthy bark (small arrow). The large arrows show the old boundary bark tissue that confined the wedge before it broke out of its confinement. Note where the cambium has been killed and compartmentalization began (double arrow).

43. Canker on red oak associated with *Strumella coryneoidea*. These cankers often are abundant on young trees and seriously alter new stands of oak. The fungus may cause some decay of the wood. The fertile, sexual stage of the fungus, which occurs after the tree breaks off at the canker and falls to the ground, is *Urula craterium* (low right). The fungus infects the bark first, then the tree produces wedges of wood into the bark (arrows, upper right). The fungus later spreads around the wood wedge and the seesaw interaction continues until the tree is killed, or the tree breaks at the canker. But in some cases, the tree walls off the fungus so effectively that the canker is stopped.

44. Chestnut blight is caused by *Endothia parasitica* (*Cryphonectria parasitica*). After the fungus kills patches of bark, some still-living portions of the cambium may "explode" with new growth of wood and bark as shown here. Another type of response to the chestnut blight fungus is the production of pillars of wood that "reconstitute" beyond the infected and killed bark. In a sense, the infected tree begins to form a "new tree" beyond the infected tree. Trees have marvelous ways of survival, built upon recognizing the injurious agent and walling it off. Then the tree goes on to generate more healthy tissues beyond the infected and dead tissues.



45. Wood wedges into bark: 1) American chestnut infected by *Endothia parasitica*, 2) Aspen infected by *Hypoxylon mammatum*, and 3) red oak infected by *Strumella coryneoidea*.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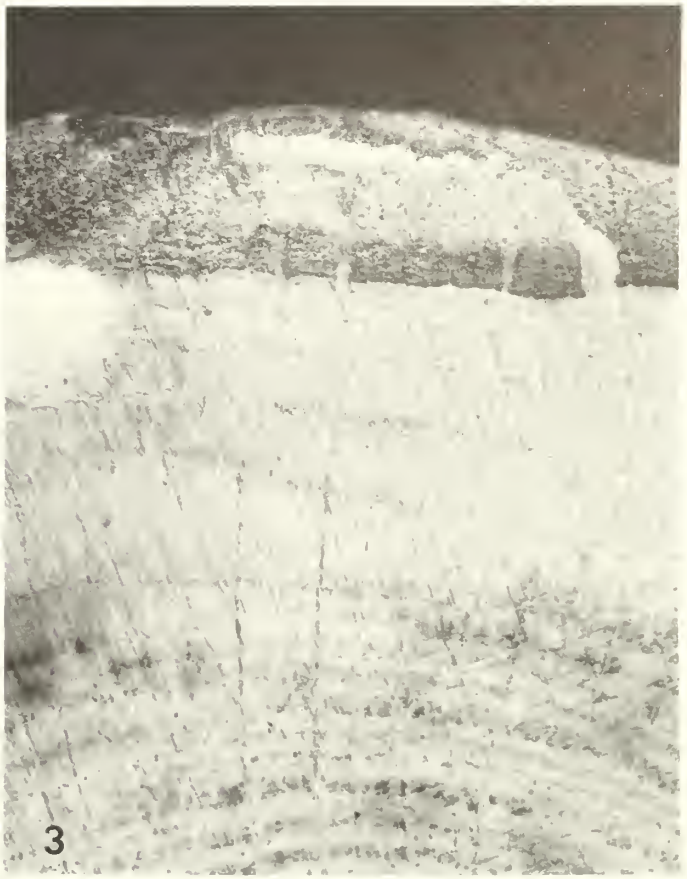

3

Interlude

To this point, many disjointed facts have been shown in the photos. No attempt has been made to connect them. The photos do give an historical account of the research. The keen observer will see in the photos much more than what is described. The keen observer will also start to perceive the sense of order that awaits and demands synthesis. If the microorganisms could move at will, they have had millions of years to do so, and trees as we now know them would not exist. If trees were able to stop all microorganisms, we would not find the many cankers and rot columns in trees that we do. Somehow, somewhere in time, some ecological evolutionary survival "deals" must have been made. We must recognize this. The basic rule: no absolutes! Trees do not "win" all the time. Yet, both must win enough of the time to assure the survival of the individual, and the survival of the group, long enough to adapt and to reproduce. What first appears as a paradox was resolved. The apparent paradox: Trees survive so long as they can avoid being digested by microorganisms. Microorganisms survive so long as they can digest trees. Both trees and microorganisms face a common survival threat—the environment. Again, an apparent paradox for environment was both very beneficial and very destructive—not only a threat, but a friend. It is the apparent, or accepted paradox that makes natural systems difficult to understand. Once we begin to understand the multidimensional mix of factors that both help and hurt, the order of things will become apparent.

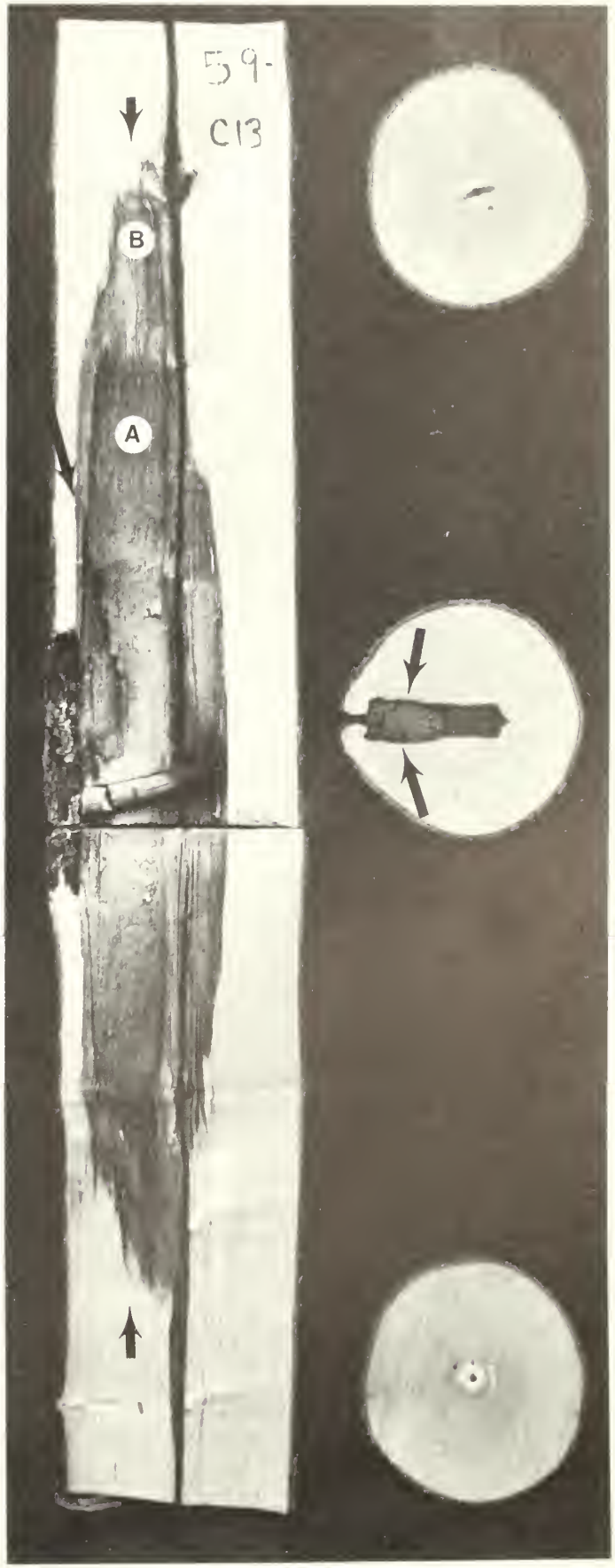
The next group of photos shows this in the results of wounding experiments, and in further dissections that show the high order of the tree survival system, and the order of the survival system of wood-inhabiting microorganisms. The concept of compartmentalization and of microorganism succession began to emerge. The paradox is resolved: Microorganisms survive so long as they infect in the orderly sequence that best fits the survival of the group—succession. Trees survive after injury and infection so long as they recognize and wall off the infected tissues—compartmentalization.

Compartmentalization is a boundary-setting survival process. Boundaries are not absolute. When boundaries are weak, or when the force of the infecting microorganisms is very strong, the boundary will fall. To survive, microorganisms and the tree must win a time game with the environment.

46. When a tree is wounded, as this red maple was with a deep drill bit wound, the tree responds by compartmentalizing the injured and infected wood. The wood is made up of many compartments. Each wood cell, with its strong cellulose wall bonded with lignin, is a compartment. Many small boundaried bodies or compartments exist within the living wood cells, especially the thin-walled protoplasm-containing cells, the parenchyma. The growth ring is also a compartment. The living strands of protoplasm that form a web of connections among the living wood cells are called, collectively, the symplast. When wood is injured and infected, the symplast connections between the infected and still-healthy wood are broken. Many chemical reactions take place to set firmer boundaries to resist, not stop, the spread of the infection. This is compartmentalization. It is a boundary-setting process to resist the spread of infection. It is not an absolute process. A model of compartmentalization has been developed. It is called CODIT, an acronym for Compartmentalization Of Decay In Trees. The model has two parts: Part I has three "walls" (two of them shown here). Wall 1 resists, not stops, vertical spread; Wall 2 resists inward spread, and Wall 3 resists lateral spread. Part II has one wall: Wall 4, which separates the infected cells from the healthy cambium. Wall 4 is a model of the barrier zone; it forms only where there is still living cambium.

3
3
2

47. Sugar maple 59-C13 was wounded and a sterile wood dowel was placed in the drill hole. After 8 years it was dissected. The length of cambial dieback above and below the drill hole is shown by dark callus tissue. When trees are wounded, the cambium usually dies back above and below the wound and sometimes the dieback will extend to the sides of the wound. The three disks were cut from the ends of the bolt and from the center directly below the drill hole. Note that the end disks have only a very small central column of discolored wood, but there is a large column of discolored and decayed wood associated with the wound. The center disk shows that the shape of the column was approximately the shape of the drill bit. Note that decay started first in the younger wood tissues, contrary to what is stated in the textbooks. The arrows in the disk represent Walls 3 of CODIT. The large arrow shows the position of Wall 4, or the barrier zone. The small arrows at the ends of the column represent Walls 1 of CODIT. Wood in area A is decayed, while wood in area B is discolored. Wood chips from area B yielded bacteria and non-decay-causing microorganisms, while wood from area A yielded mostly decay-causing microorganisms. Because the wound went through the pith, Wall 2 was not operating. Wall 2 only resists spread inward to the pith.


59-
C13
B
A

48. Tree 304S had no decayed wood associated with the wound. The column was very short. In the dowel experiments, many dowels were preinoculated with several decay-causing fungi. After 8 years, only a fourth of the introduced fungi were recovered. But, even when they were recovered, the decayed wood was within the outer column of discolored wood that yielded, on isolation, bacteria and non-decay-causing fungi. The concept of microorganism succession does not mean that bacteria ALWAYS came first, then non-decay-causing fungi, then decay-causing fungi. Definitely NOT SO! Succession means the orderly sequence of microorganisms. The order is such that the survival of individuals and groups is maintained in relationship to or in association with the specific environmental and other conditions. In some cases, it is possible that decay-causing fungi will be the first microorganisms to interact with the tree. Natural systems do not come in absolutes.

The wounding and inoculated dowel experiments were done in oaks also (also black cherry, white pine, and American beech). When heartwood was wounded it discolored. And the shape of the discolored column as viewed on the cross-sectional face of the central disk was the shape of the drill bit. The oak heartwood did compartmentalize the injured and infected wood. But, is not heartwood a dead, non-responsive tissue? It may be dead according to our definition, but it must be responsive, or at least reactive, to wall off the injured and infected wood.

304
304
S

49. When wounds or dying branches expose the wood of oaks to microorganisms, the sapwood begins to decay first, not the heartwood. This section of an oak shows the decay of the sapwood. Note also that the tree begins to wall off the decay at the base of the branch. When large oak branches die, and the central core is heartwood, the sapwood-rotting fungi decay the sapwood rapidly, thus leaving a core of strong heartwood. When such branches break, they do so a meter or more out from the trunk. When oak branches die before large cores of heartwood form, they usually break close to the trunk.

50. Other studies on red oak showed conclusively that heartwood does discolor, and that some of the changes that take place in the discoloration process are not so different from those that occur in maples. The infections did not spread into the center of the tree. The injured and infected wood was compartmentalized. But when other oaks were killed by basal girdling first, and then wounded, there were no sharp boundaries showing the outline of the drill bit in the heartwood. These studies indicate that heartwood will react when injured and infected. The exact nature of the reaction is still not clearly understood. We know only that it is orderly; it repeats. Also note that decay starts at the inner side of the sapwood and not deep in the heartwood.

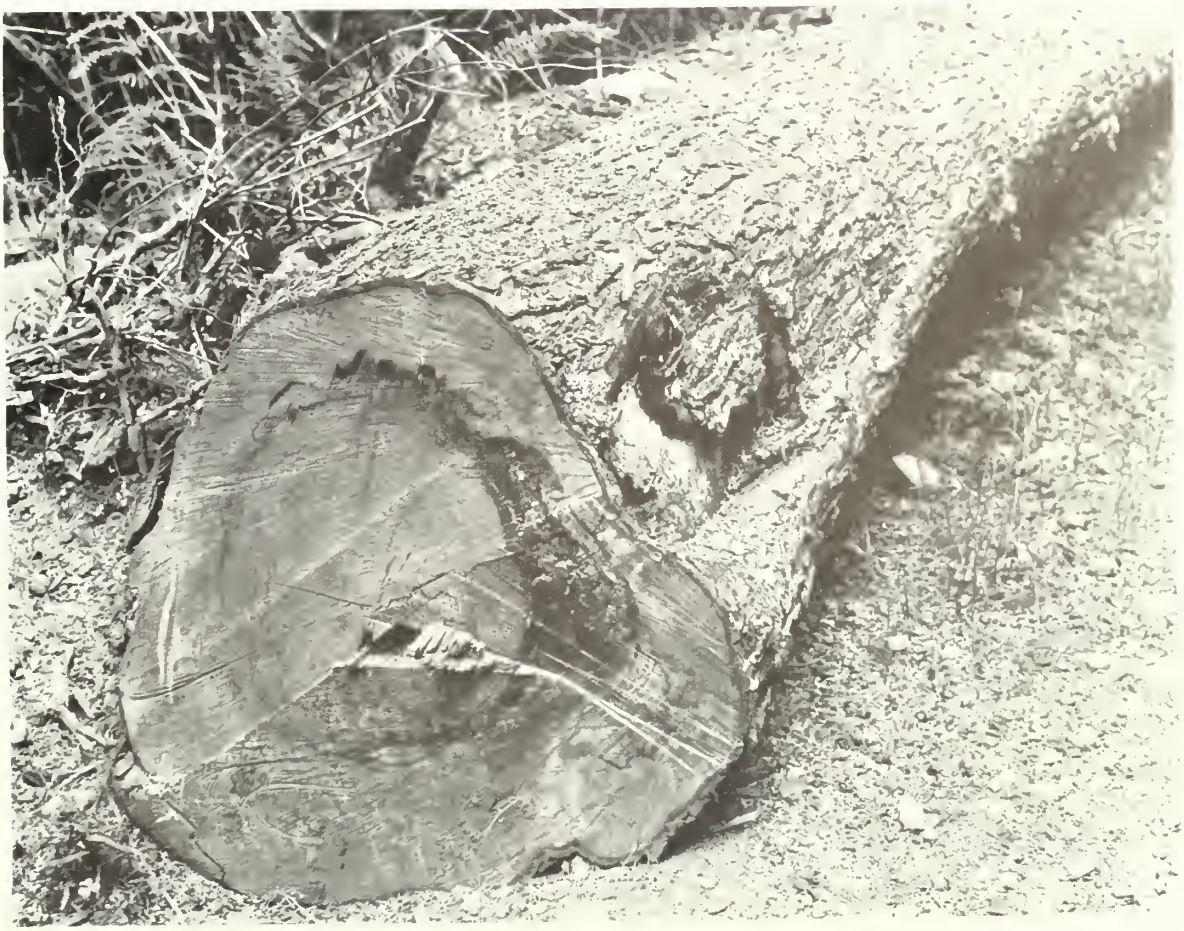
51. Examination of naturally inflicted wounds and other wounds, such as this buckshot wound on a red oak, shows that the same principles are functioning, and the CODIT model is applicable in heartwood. Note the margin of discolored heartwood surrounding the decayed wood. Note also that the decay did not spread outward into the heartwood that formed to the outer side of the decayed wood. If the fungi are "heartwood rotting" then why don't they spread into the heartwood only one growth ring away? A barrier zone, Wall 4, separates the decayed heartwood from the sound heartwood. Research by investigators at Oxford has shown that barrier zones in red oak contain suberin. It may be that barrier zones separate because they are like an inside bark. This sample shows the highly ordered compartmented make-up of trees. Oak wood is ring porous. It has large spring vessels, and much smaller vessels in the summer. The radial sheets of parenchyma are very pronounced. Note also (at the center) the five-lobed shape of the young oak tree.

4
3
3
2

52. This dissected, experimentally inflicted wound in a sugar maple is very similar to the wound in oak shown in Figure 51. The decayed wood is surrounded by discolored wood. The Walls 2, 3, and 4 are very effective. Maple is a diffuse-porous tree. The spring and summer vessels are the same size, and the vessels are equally distributed in the growth ring. The radial ray sheets are not pronounced as they are in the oak.

53. A natural wound on a large Sitka spruce shows the same pattern as those in the oak and maple. Conifer wood has a different tissue arrangement.

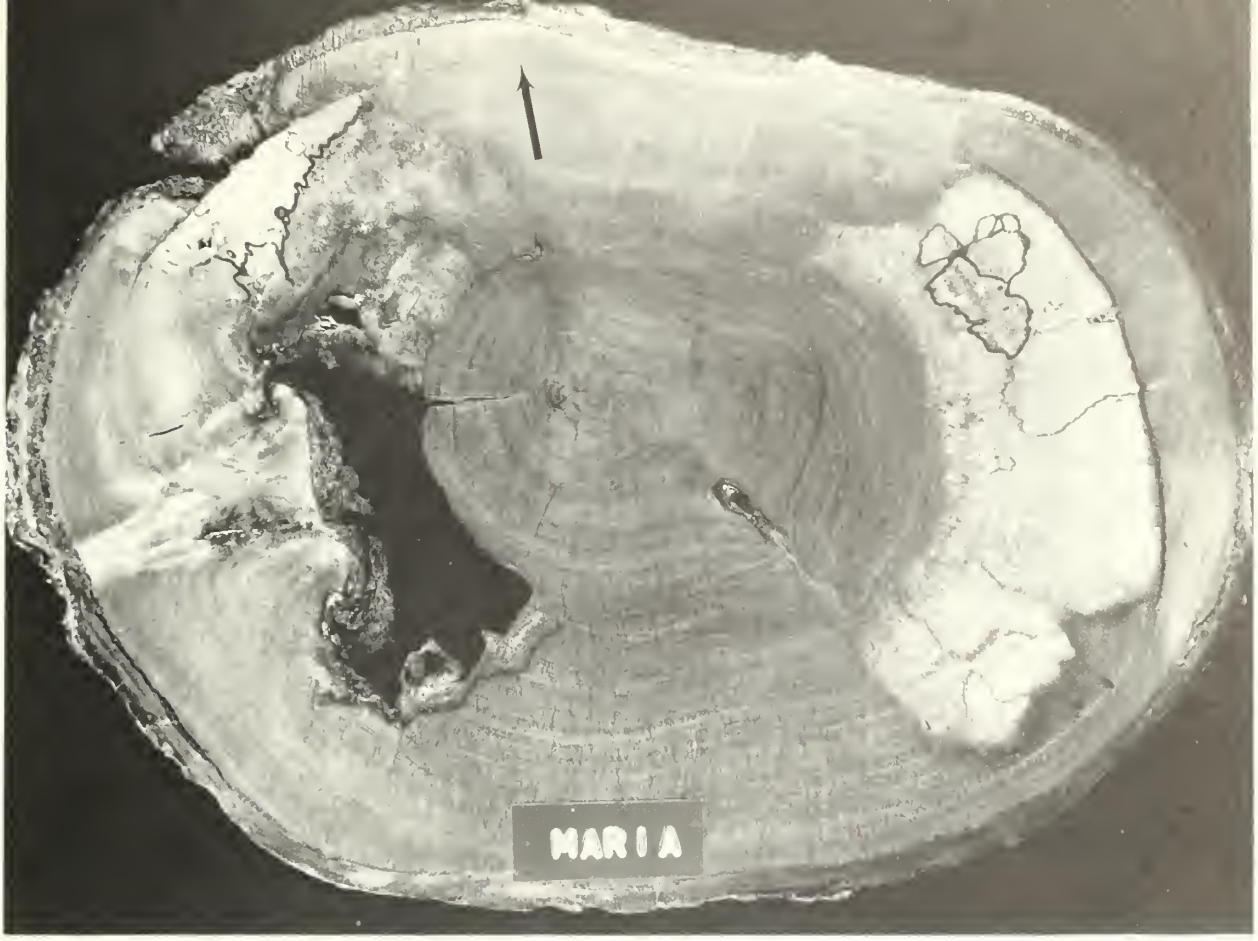
4
3
2
2
4
3



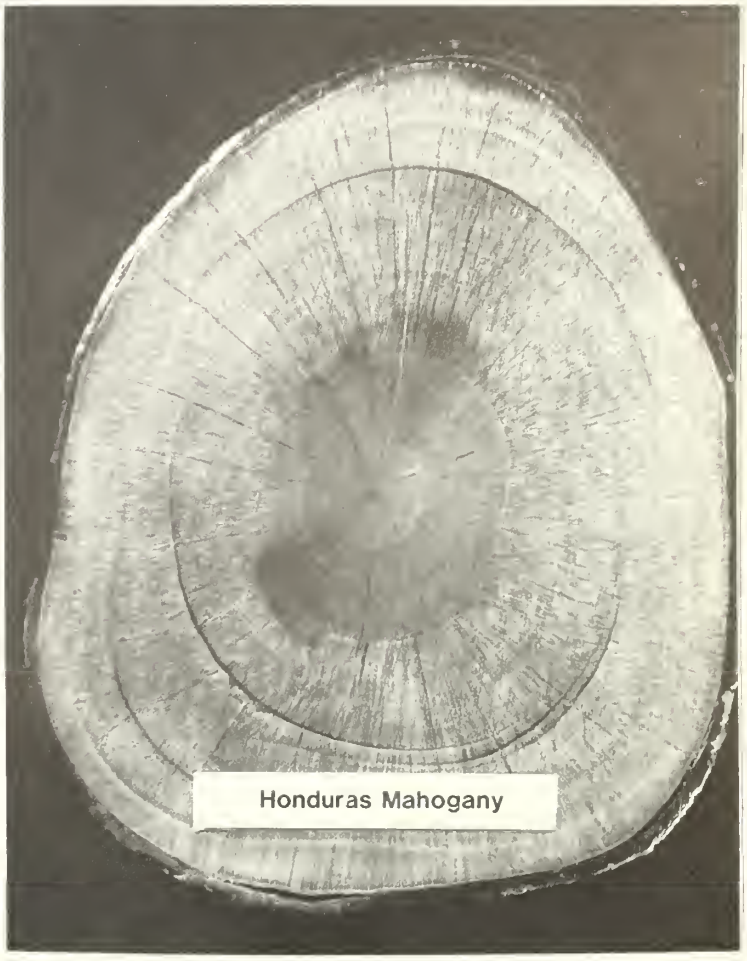
54. Tropical hardwoods also follow the CODIT model. The arrow shows the obvious barrier zone. Indeed, microorganisms do not have "free run" in the heartwood. Heartwood does compartmentalize.

55. A pattern similar to that shown in Figure 54 is shown here in an American beech. The central column of discolored wood was sound (A). The column of decayed wood (B) associated with the large branch core wound did not spread into the central column, nor did it spread rapidly into the surrounding columns of discolored wood (C). The CODIT boundaries are not absolute, but they serve as a guide to the spread of microorganisms in trees.

56. The bold barrier zones are easily seen in this mahogany. The barrier zones are often the initial sites for wood separations in living trees and on into wood products.

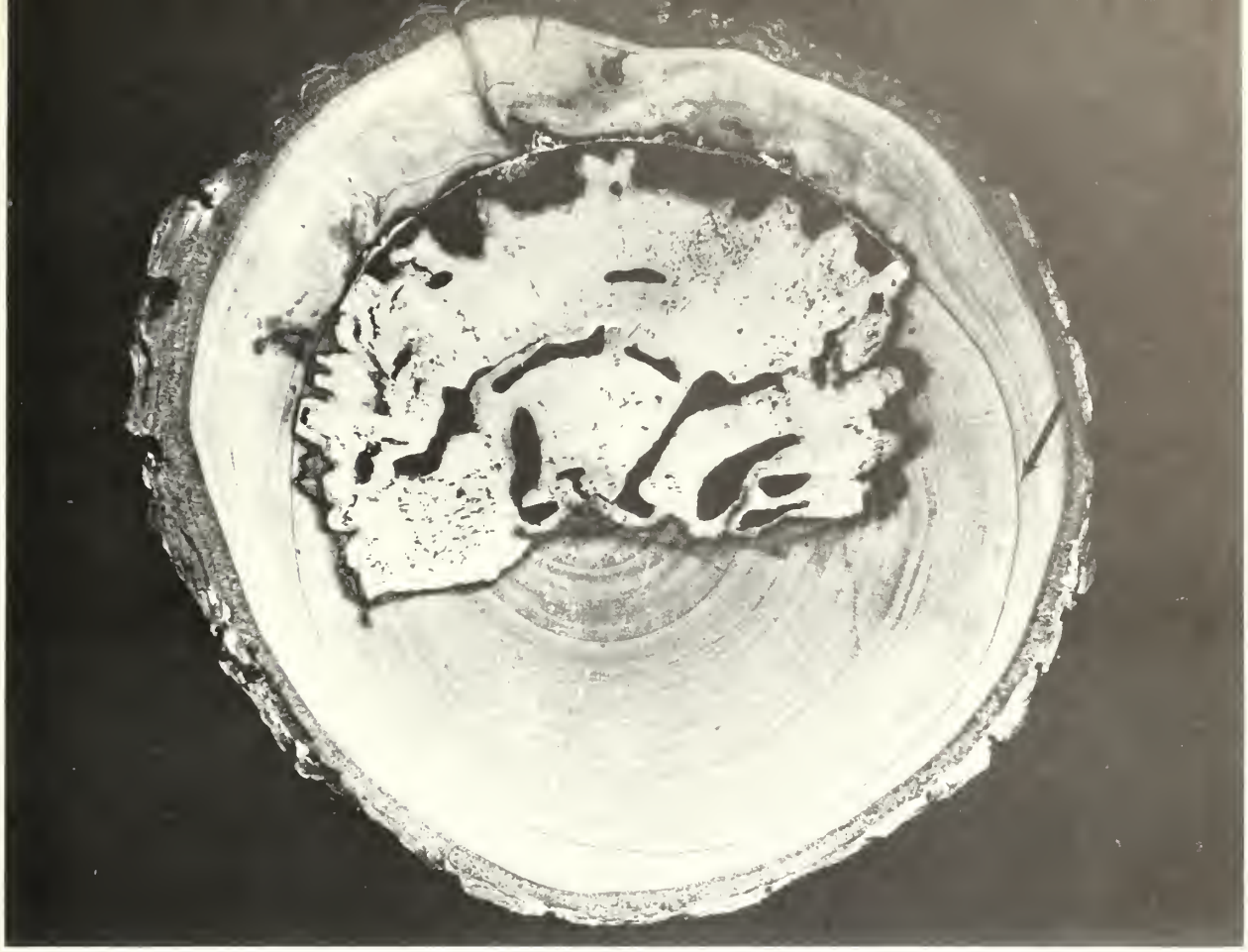

MARIA

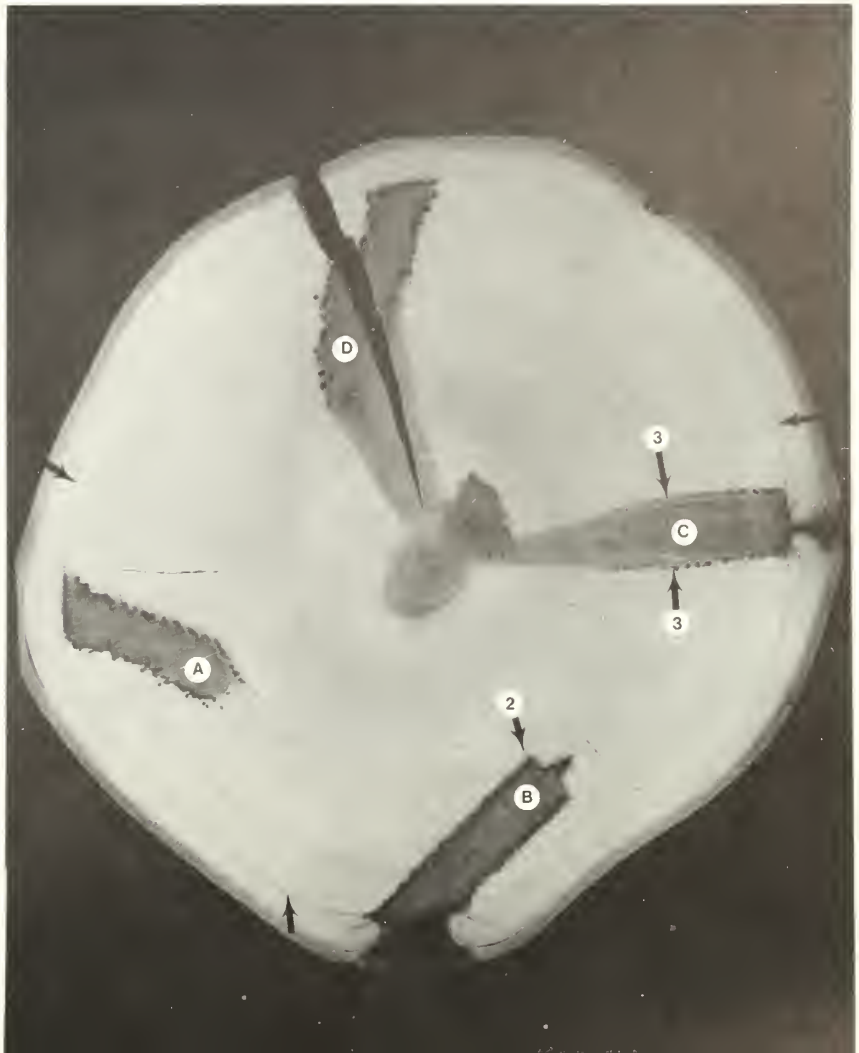
A
B
C


Honduras Mahogany

57. The barrier zone may form only a short distance, or it may develop entirely around the tree as shown here in a sweetgum injured by a beaver. The arrow shows the barrier zone. Note also that the insects that infested the decayed wood stayed on the inner side of the barrier zone. The decay spreads as Walls 3 recede. Once the pith is reached by an organism, Wall 2 is no longer in operation. The decay spreads as an opening fan. Why the barrier zone is sometimes extensive and sometimes not, is not well understood. Sometimes even small wounds stimulate large barrier zones, while large wounds may have very small barrier zones. Indeed, much is yet to be learned.

58. The barrier zones associated with the four experimentally inflicted drill bit wounds coalesced to form a complete ring (small arrows). The wood on the inner side of the barrier zone was very slightly darker than the wood that formed after the tree was wounded. Drill wounds A and B were slanted and the internal tips of the wounds were not close to the central column of discolored wood. Drill wounds C and D were close enough to the central column that Walls 2 could not hold: the tissues between the internal tips of the wounds and the central column were isolated, and they died and discolored. Walls 2 did hold for wounds A and B. When new wounds are inflicted in a tree, much that happens internally will depend on what is already in the tree. If the wood is all clear, then the new wounds will be effectively compartmentalized. But when new wounds meet with, or come close to, older inner columns of discolored or decayed wood, compartmentalization may not be as effective. Only Part I of CODIT or Walls 1, 2, and 3, can operate at the time of wounding because the next year's tissues are not there yet. It is possible that Walls 1, 2, and 3 may respond so poorly that the cambium does not survive. Trees do die. Microorganisms do win.



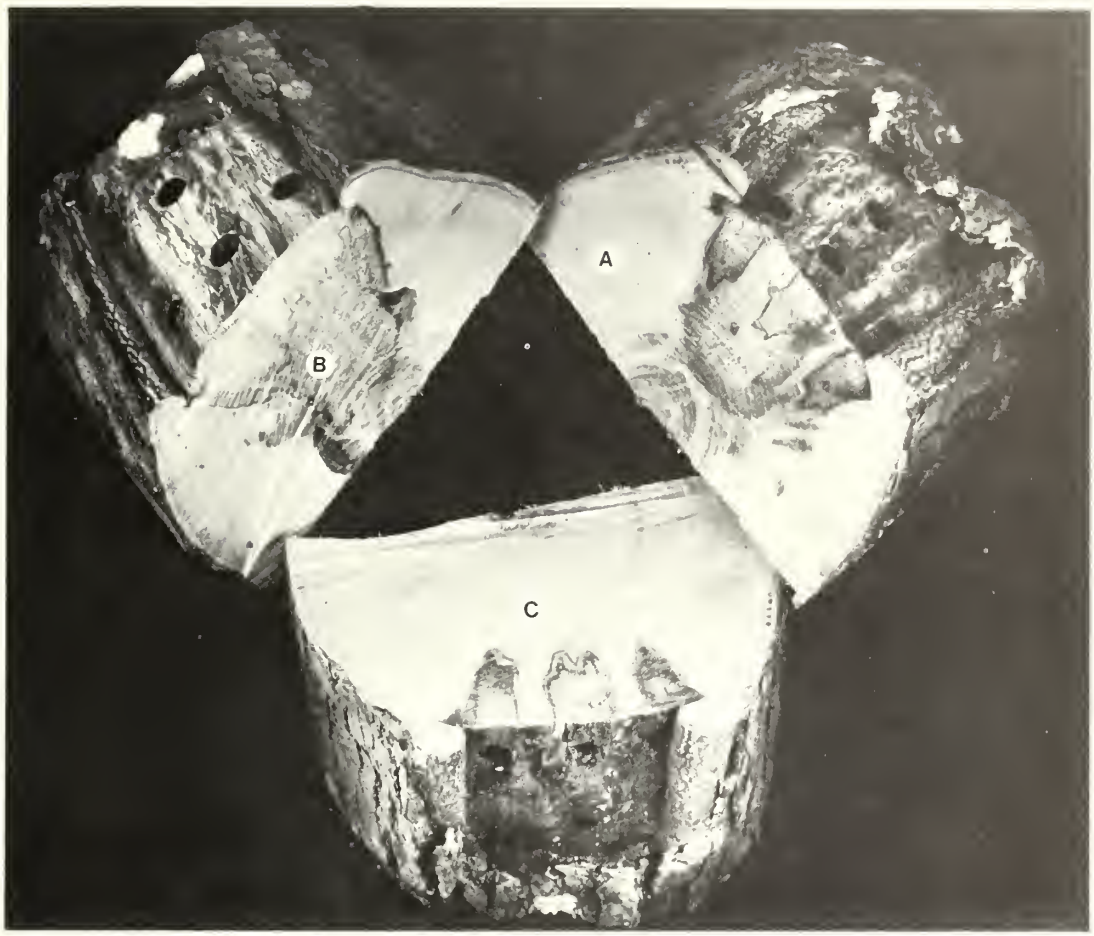

D
3
C
3
A
2
B

59. Sections from four paper birch (PB) and yellow birch (YB) trees, wounded experimentally with four drill bit wounds each, show the variations in internal response. Tree genetics cannot be discounted. Some individual trees in a species do compartmentalize better than others. Trees YB-A and PB-A were clear to the pith before wounding. This indicates that the trees walled off branch stubs very effectively without having columns of discolored wood spread from the inner branch core wood into the tree trunk. The drill wounds were in clean, healthy tissues, not affected by past columns of discolored wood. The new columns from the drill wounds were effectively compartmentalized. In trees YB-C and PB-C there were large columns of central discolored wood before the drill wounds were inflicted. The large central column suggests that the trees did not effectively wall off discoloration spreading into the trunk from dead branch core wood. The drill holes into trees YB-C and PB-C resulted not only in larger columns of defect, but more decayed wood. Thus the genetics and the wounding history of the tree play major roles in how effectively it compartmentalizes new injuries.

A
YB
C
YB
A
PB
C
PB

60. These samples from the same red maple tree show the single effect of internal defects present when new wounds are made. The red maple received three combination drill-hole and scribe wounds as shown. Wounds A and B had much larger columns of decayed wood than wound C. Why? Wound C was at the base. Studies on many other trees showed that basal wounds usually—but not always—produce smaller columns of decayed wood than wounds higher on the trunk. Bases of most trees are broader than the upper trunks. Also, most columns of central discolored wood associated with dead branch core wood attenuate as they develop downward. So new wounds higher on the trunk usually come closer to older internal columns. Wounds A and B had only a narrow band of healthy wood separating the new wood from the central column. It was not enough to hold Walls 2. Wound C was separated by a large band of clear wood from the very small circle of discolored wood at the pith. Compartmentalization worked very well for wound C.

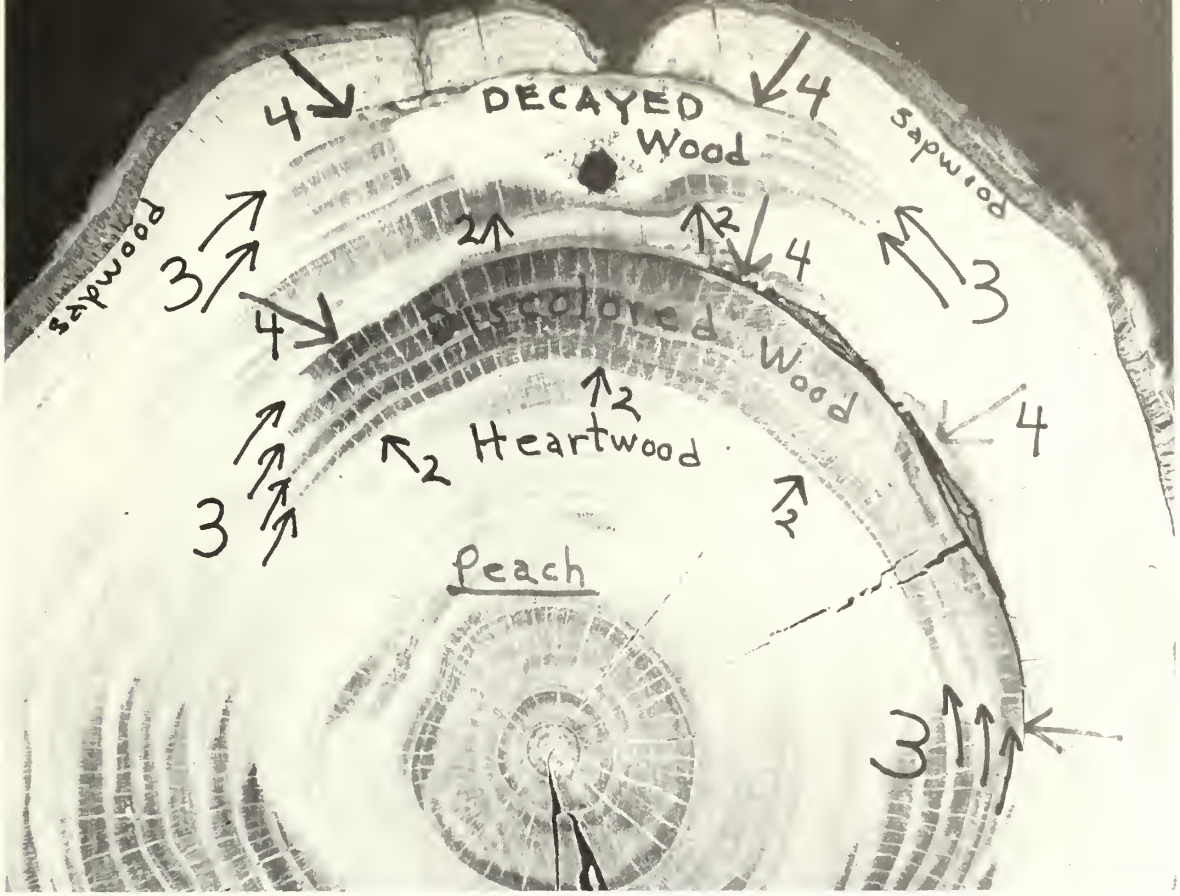
61. Studies on hybrid poplars were the first to suggest that the degree of compartmentalization may be under genetic control. Fourteen deep drill holes were inflicted in each of many trees, of many different clones. After 2 years the trees were dissected. All trees in some clones had very little discolored wood associated with the wounds, while trees in other clones all had large columns of discolored wood. The two sections shown here are from the best and worst clones. All clones were the same age and they were grown on the same site.

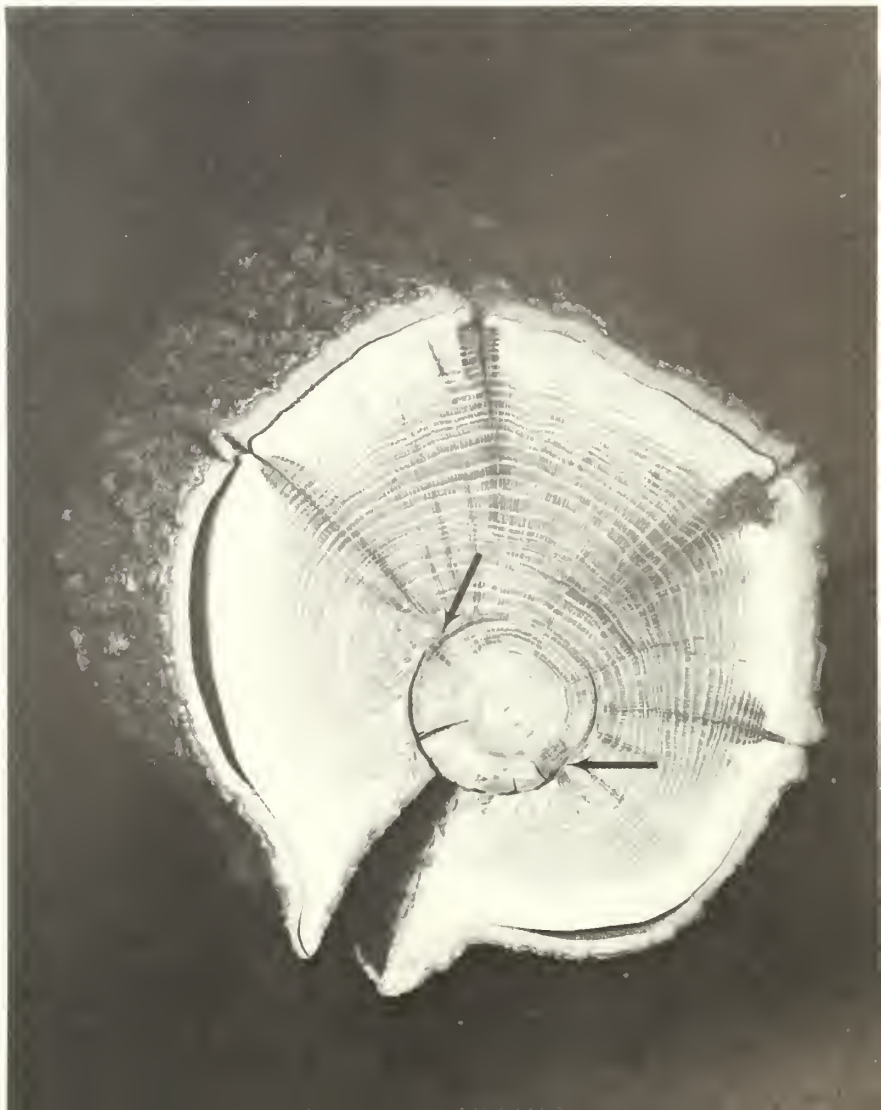

A
B
C

62. This peach sample summarizes many of the points made in the group of photos. A discolored column is compartmentalized within the heartwood. A column of decayed and discolored wood is associated with a more recent wound (the hole is where a wood sample was taken for isolation of fungi).

63. Cracks are among the most serious defects in trees. Cracks often start after the trunk has been injured. Oaks commonly have long vertical basal cracks, called "frost cracks". Frost does not start the cracks; wounds do. Old basal fire injuries on oaks are common starting points for cracks.

This basal section of red oak shows the internal cracking pattern. The arrows show the circumferential extent of the injury. Note the closure starting with the inroll of the growth rings. Where the inrolling growth rings meet, a primary vertical or radial seam formed. The primary seam is open on this sample. After injury, a Wall 4, or barrier zone, formed, and outward in a radial direction many secondary seams, or shakes formed. Some of the seams split out to the cambium. Often the secondary seams are more serious defects than the primary seam.

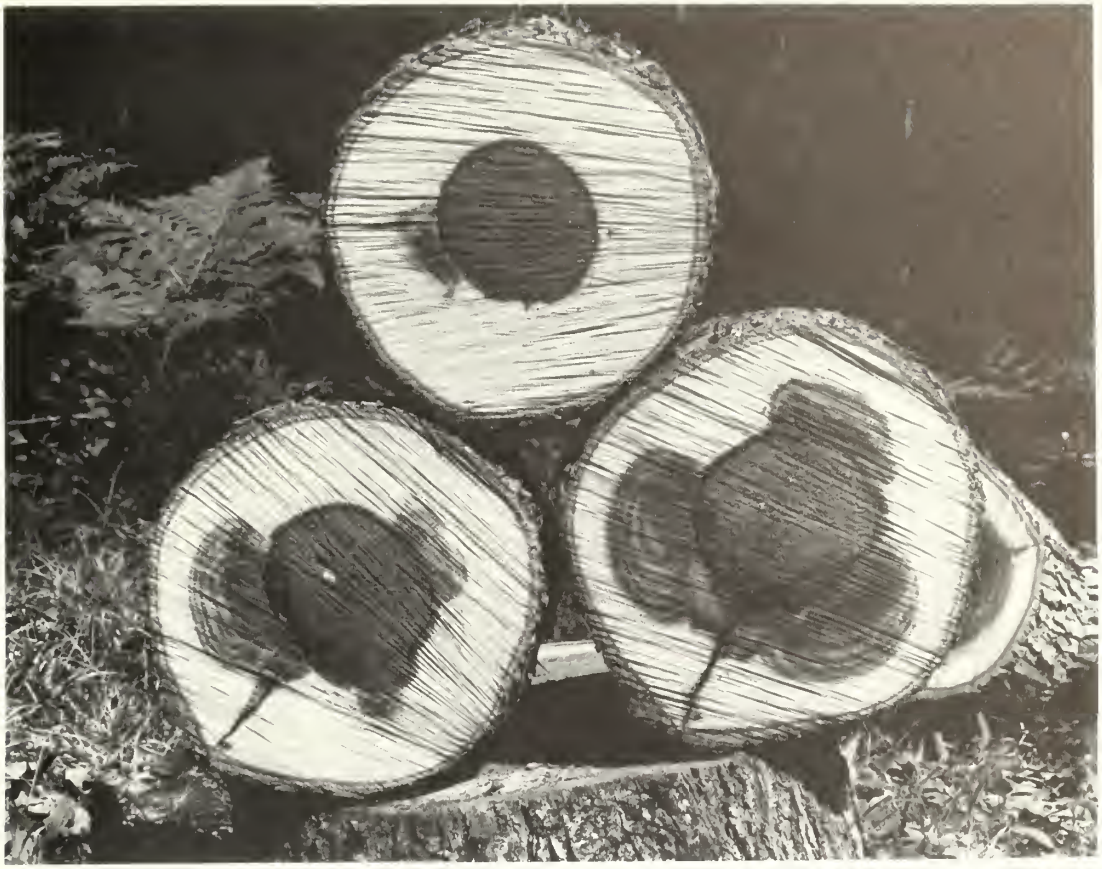

DECAYED
Wood
sapwood
sapwood
Discolored
Wood
Heartwood
Peach
4
4
3
3
4
2
2
2
2
4
3
3

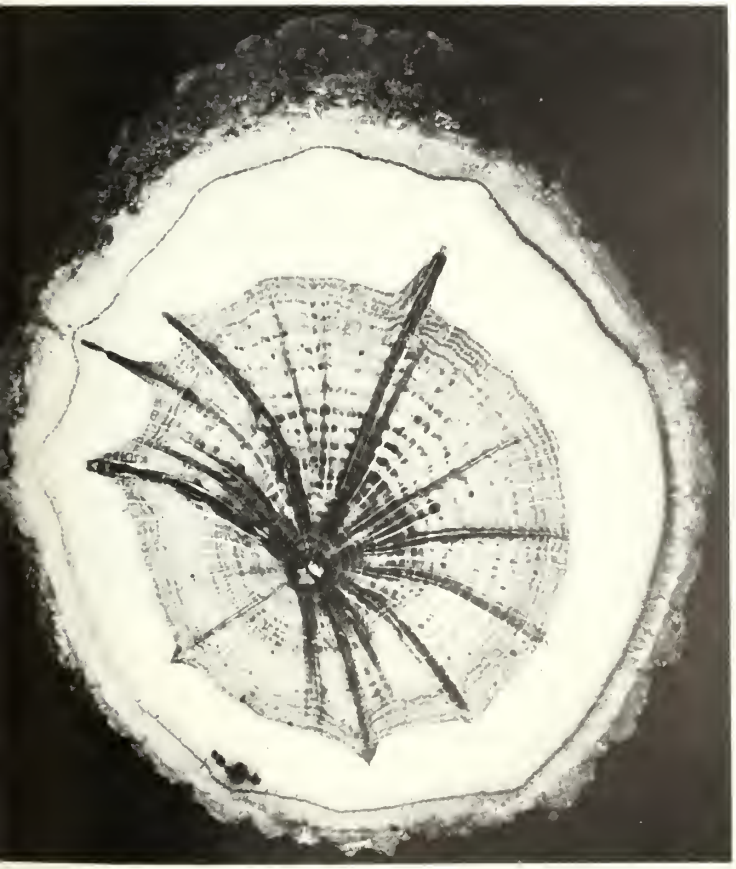


64. When very serious wounds are inflicted, heartwood formation may be stalled. The wood present when this white oak was wounded was decayed to an advanced state. Note the erratic pattern of heartwood formation. The upper section looks as if no heartwood had formed.

65. Radial cracks splitting outward from the central defect. It is not uncommon for oaks to have very small central columns of discolored and decayed wood, associated with wounds that were inflicted when the tree was very young. These became the starting points for cracks. This pattern is often called spiderheart or heartshake. The pattern is also common in planted pines that were injured at the time of planting. The same patterns and problems occur with orchard trees that receive wounds at the time of planting.

66. This black walnut was wounded when it was less than an inch in diameter. As the growth ring inroll started, it started a radial seam. In later years, if the tree had not been cut, it would be difficult to understand how a crack on one side of the base was started by a wound on the other side.





67. Discolored wood often develops along the crack zone. The arrows in this red maple show the barrier zone and the starting point for the cracks. Cracks pose difficult problems for trees. Only Walls 3 can effectively hold the cracks to some reduced size. When cracks break out to the cambium, the tree responds as it would to a new wound. But there are limits to the compartmentalizing effect, because further splitting may continue from the inside outward. Some decay-causing fungi often follow the cracks outward, and can spread throughout heartwood this way.

Long cracks are also common in many conifers, especially western hemlock. Old fire wounds and logging wounds are usually the starting point. When long cracks develop at opposite sides of a tree, this is a serious sign for a potential hazard tree. Cracks should be the first sign to consider when assessing trees for potential hazards. Why some wounds lead to cracks while others do not still needs clarification. It does appear from dissections that the wounds that do lead to cracks are those that are inflicted on smaller trees, and especially rapidly growing smaller trees. The growth ring inroll then closes rapidly and may actually "cut in" at the edges of the wound. The formation of barrier zones also plays a major role in cracking. Factors that favor a large barrier zone also favor ring separations that will favor radial cracks. Many wounds can be prevented, and they must be if we are to grow healthy, high-quality trees.

68. Big trees with big defects are not very valuable. One of the most damaging defects on most species of conifers is ring rot, caused by the fungus *Fomes pini* and some of its variants. Because of the ring patterns of defect, it is often impossible to cut clear boards. Small amounts of ring rot do not cause serious damage to construction timbers. The tree being cut here is a Douglas-fir in the Pacific Northwest.

69. Decays caused by other fungi are also serious defects in many species of conifers. The CODIT model is applicable to these defects. The small arrows show the walling off of an advanced column of decayed wood. Note also the triangular shape of the decayed column. The medium-size arrows show an old Wall 4 and out from it are cracks and decayed wood along the cracks. The large arrow shows the end of a wound, the circumferential crack or shake, and the radial crack splitting outward.

70. Fruit bodies of *Fomes pini* usually form where the old branch wood protrudes. Below this stub is the fungus material that acts as a wedge into the bark. When the wedge kills cambium, the tree responds by producing resin-soaked wood.

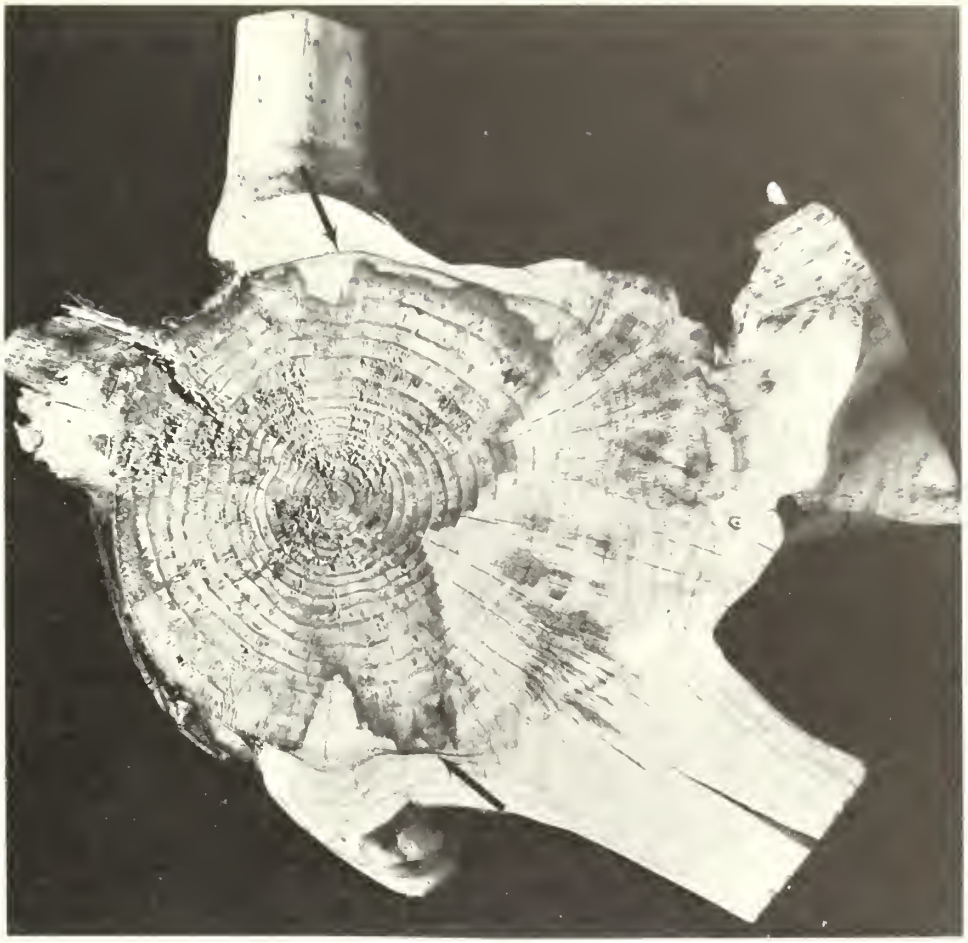
71. The fungus material is below this broken stub. The tree produces the resin-soaked material in the aging sapwood at the sapwood-heartwood boundary. This results in a strip of decayed wood with sound wood on both sides.

72. When the stubs fall away or are decayed away, the fungus material forms a plug in the branch stub area. This plug of fungus material is called a blind knot, or punk knot. The knot is often covered with old bark plates and resin, and may be difficult to identify. Most decay-causing fungi do not attack the inner core wood of branches, but *Fomes pini* does. The fungus appears to become established in resin ducts, hence the fleck-type pattern to the decayed wood. It may be that the fungus cannot advance into the sapwood because of the very large amount of resin material that separates the sapwood from the fungus. It may be that the concentration of resin materials at the sapwood-heartwood boundary suits the fungus. Regardless, the fungus does spread in the discolored and partially resin soaked growth rings at the sapwood-heartwood boundary. This results in the typical ring pattern. In some trees *Fomes pini* invades the entire central wood and no ring pattern forms. This is common in spruce and can occur in Douglas-fir.

73. Root rots cause serious problems to trees. One of the major root rots is caused by *Fomes annosus* (*Heterobasidion annosum*). The fungus does kill roots. When the tree recognizes the infection, compartmentalization begins. The tap root in this red pine was killed by the fungus. As the fungus spread upward it was walled off by the tree (arrows). The wood that continued to form after infection was compartmentalized and clear. The arrows show the barrier zone that separates the infected wood from the healthy wood. When so much of the tree is walled off, a critical point may be exceeded, and the entire tree may die. Compartmentalization is beneficial in small amounts, but in large amounts it may be counterproductive.

74. Another root rot that causes major problems worldwide is incited by *Armillaria mellea* and related species of *Armillaria*. The disease is often called "shoestring root rot" because the fungus produces long strands of fungus tissue that resemble black shoestrings. The "shoestrings" are rhizomorphs. They often entwine around healthy roots as well as weakened roots. After stress, weakened roots may be infected, or the rhizomorphs may grow into the root. Basal sprouts often form around trees killed by *A. mellea*.

A root of red spruce killed by *A. mellea* (arrow). The dead root is walled off as it enters the larger root. Larger roots continue to wall off smaller roots, until a threshold is reached and the larger root dies. Then the sequence of walling off continues upward until the butt and trunk are met. When so much of the tree is walled off, death follows. Most trees infected with *A. mellea* persist for long periods with many infections. After the threshold is reached, death comes quickly. It is the "sudden" death that is recognized.



75. *Armillaria mellea* infects bark first, and then the wood. The fungus spreads in bark until it is recognized and compartmentalized. It is possible that the fungus could girdle roots before it was recognized. In this red spruce butt the small arrows show the extent of the original bark infection at the time of compartmentalization. The fungus spread again later in the bark, and was recognized and compartmentalized at the position of the large arrow. Note that the decayed wood at A did not spread into the center of the tree. *A. mellea* appears to spread most rapidly in sapwood or wood that still has some living cells at the time of infection. Roots compartmentalize just as trunks do.

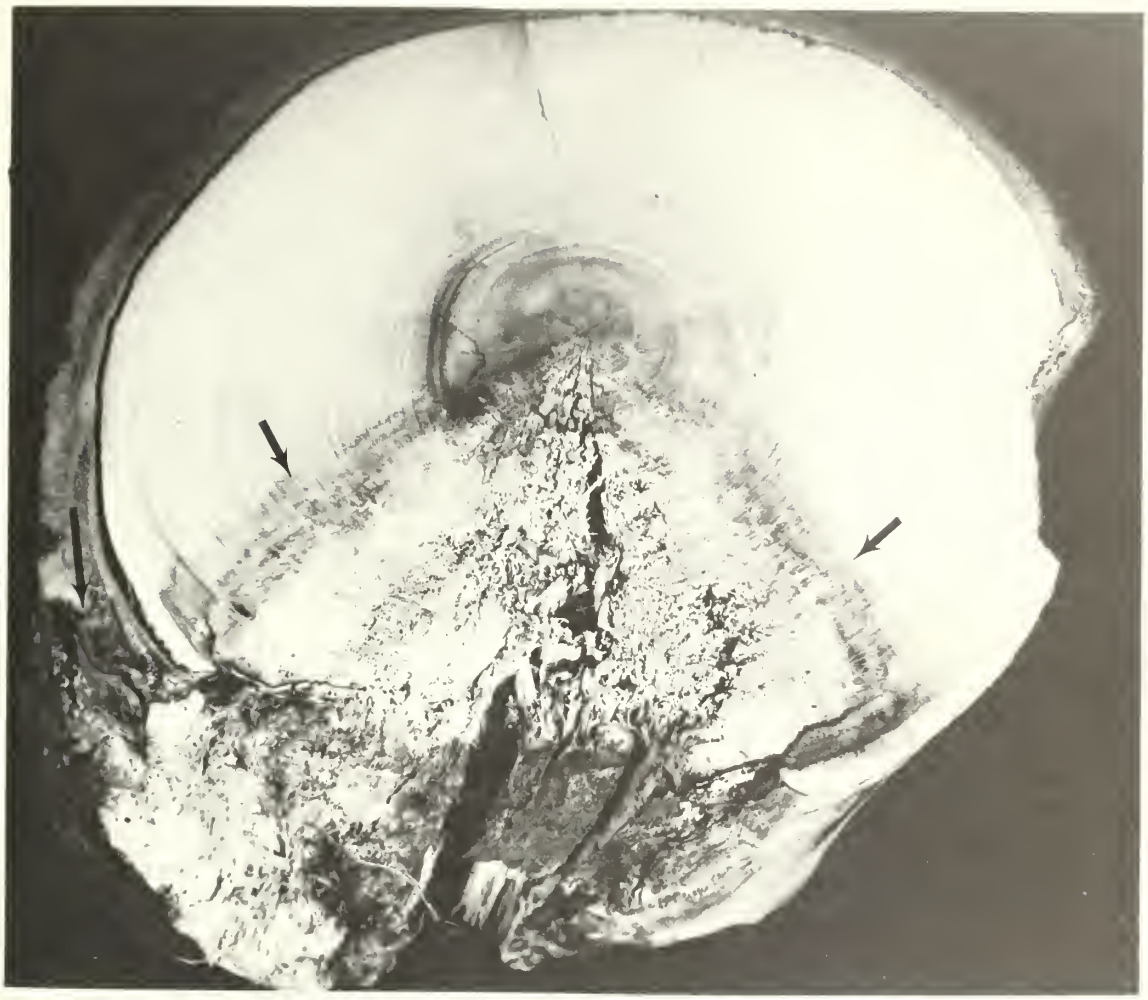
A

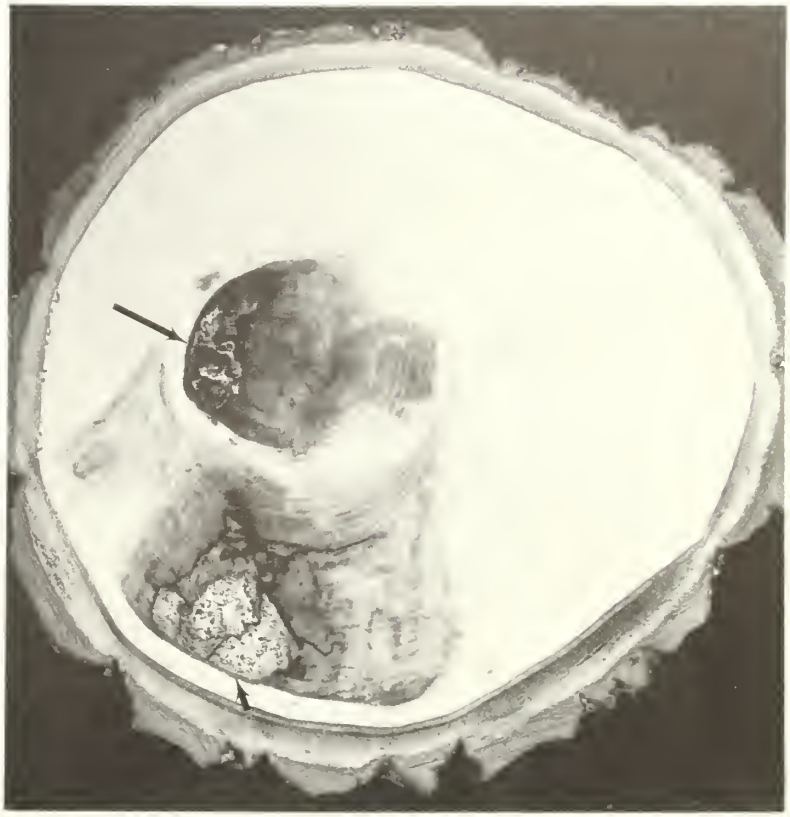
76. Dissection of a basal section of a Balsam fir. The lower portions of roots are infected and decayed first. The bottoms of the roots have a tissue connection with the between-root portion of the tree base; thus the decay spreads upward from the bottom of the root to the tissue between the roots. The infected wood is compartmentalized from the upper section downward. It appears to be spreading outward, but as viewed from the lower sections upward, is actually moving inward. Wetwood develops in the same way, from the roots upward.

77. Butt of aspen with an old infection of *A. mellea*. The infection killed the large root, and spread laterally and upward into the trunk about 18 years before the tree was cut. The small arrows show the size of the root when the infection was compartmentalized, and the large arrow shows the size of the trunk base when the infection was compartmentalized. Note that the infection did not spread inward to the center of the tree, but inward to another barrier zone from another injury.

78. A lower trunk section from an aspen infected by *A. mellea*. The decayed wood spread to the center here because no older barrier zones were encountered. Note the infection in the bark (large arrow). Walls 3 resisted lateral spread (small arrows). Discolored wood bordered the decayed wood. It may spread for great distances in the wood, far beyond where it was stopped in the bark. But, where it spreads in the wood, it spreads only in the wood present at the time of bark infection. The fungus does not move outward radially to infect bark again.

79. A lower trunk section of aspen infected by *A. mellea*. The large arrow shows Wall 4 associated with an older column of decayed wood. The small arrow shows Wall 4 associated with a more recent infection. The decayed wood may spread for a great distance within the wood present at the time of infection.





80. Multiple cracks on balsam fir indicate serious internal decay and internal cracking. Cracks at the base of balsam fir usually indicate root and butt rot. *A. mellea* is usually, but not always, the fungus involved. Resin often flows from old branch core sockets on trees infected with root rot. Trees with basal cracks should be cut as soon as possible. Some forest areas are root-rot areas because the fungus is kept vigorous on dead roots of cut trees. When balsam fir is cut, more balsam fir grows again. Root rots are common in many fir areas.

81. The basal section of the tree shown in the previous photo shows the central hollow and the radial cracks splitting out from the hollow. A great amount of wetwood is associated with the roots and the butt. Trees with root and butt rot often break near the base. Such trees in an area indicate a root rot zone.

82. Large collar cracks form on root-rotted birch. Trees with such collar cracks should be cut as soon as possible.

Collar cracks start when support roots are rotted. Cracks that start at the butt spread upward.

Armillaria mellea and its related species infect many species of trees worldwide.

Pause

CODIT is a model of compartmentalization. Compartmentalization is a highly ordered boundary-setting process to resist the spread of infection. The process is not absolute. It does not function perfectly all the time. When it does not function effectively, some part of the tree, or the entire tree, may die. Our responsibility is to understand the natural processes of buildup and breakdown well enough to be able to prevent, detect, or regulate them. And when this cannot be done, then predict their movement over time accurately. In forestry, the group of trees must be considered. In urban forestry or horticulture, or in orchards, the single tree must be considered. Treatment of trees to prevent and "cure" diseases has been a personal art form. Many treatments arose from practices used in human medicine. It is time to reexamine many tree care practices on the basis of new information and of new pressures inflicted on trees. Science is a constant reexamination process in search of, and in documentation of the truth. Truth is order.

The more we understand the order of natural systems, the more we will be able to make the best decisions, most of the time. Some common tree treatments have been reexamined:

wound dressings, cavity filling, wound scribing or tracing, cabling and bracing, injections and implants, and most important, pruning. For the good of our trees, some adjustments must be made.

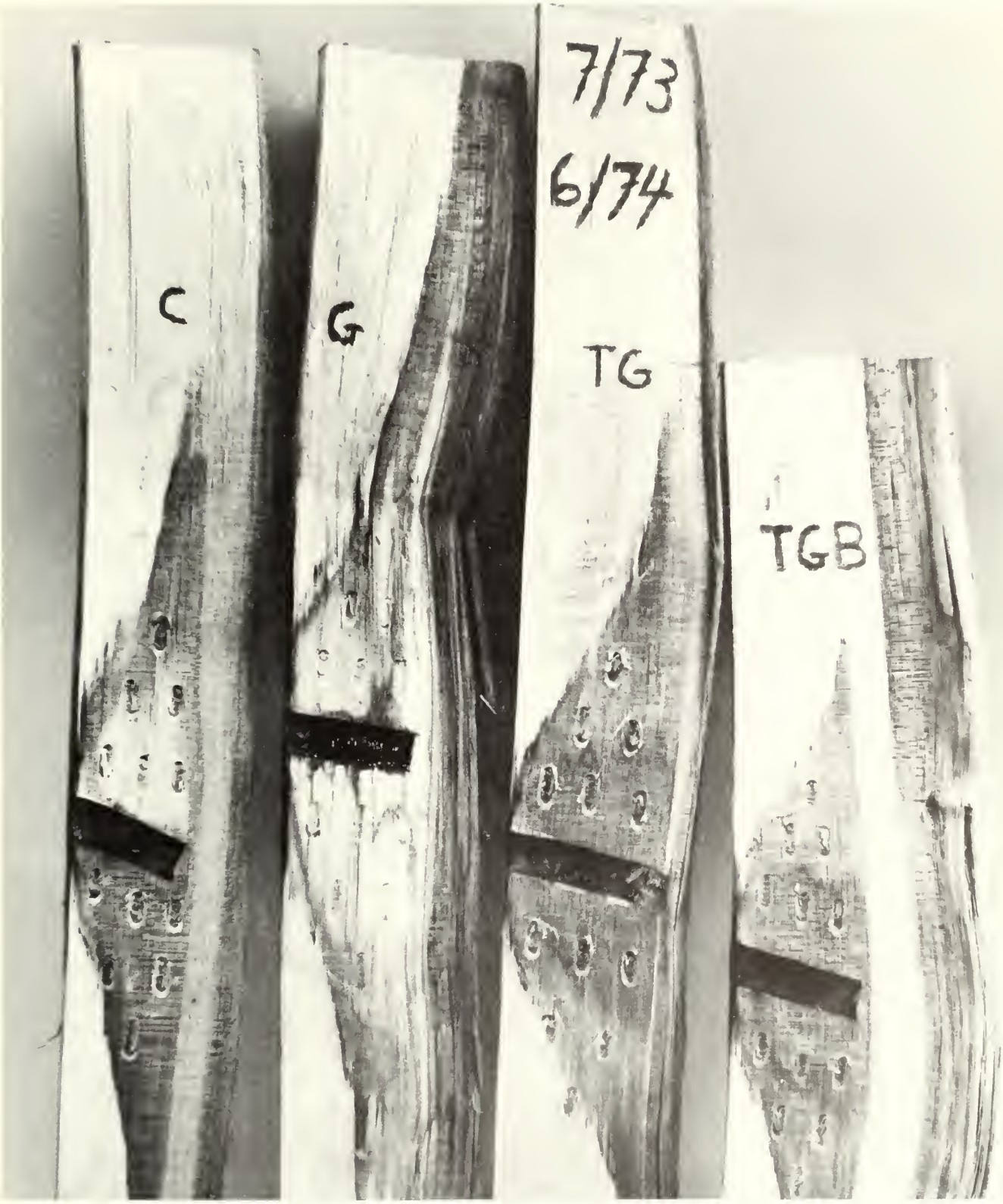
83. Wound dressing has been the hallmark of the arborist. Wound dressings were used to prevent or stop decay, but there are no data to show that any wound dressing prevents or stops decay. Studies that included dissections and isolations showed that trees with wound dressings were no better off than the untreated controls. The four wounds on the left were on one red maple tree, and the four wounds on the right were on another red maple tree. The dark-faced wounds were coated with a common wound dressing. Note the dieback associated with the wounds. Dissections showed no difference between the two trees in the amount of discolored and decayed wood. This photo was taken 1 year after treatment. Bark was removed to show the dieback.

84. Seven-year old treated and control wounds on seven red maple trees. Each tree received four wounds, three of them treated and one control. The treatments were a very common black asphalt-based dressing, orange shellac, and a rubber-type material, plus the untreated controls. Note similarities in callus formation and dieback pattern on the four wounds from each tree—four per horizontal row. Note also that some dressed wounds have no decay associated with them while others do. Why? A closer look will explain why. When the experimentally inflicted wounds injured wood very close to inner defects, decay developed. When there was a wide band of healthy wood separating the inner defect from the experimentally inflicted wounds, no decay developed. These results show again the importance of wounds that decrease the volume of healthy wood in a tree.

Seven red oak trees wounded and treated the same as the red maples were also cut and dissected after 7 years. The strong effect of individual genetic traits was shown with the oaks. Some trees closed all wounds, regardless of treatment. No wood decayed, and there was only a small column of discolored wood.

85. Agents of biological control were also tried in wounding experiments. Results of studies showed that when a non-decay-causing fungus *Trichoderma harzianum* was introduced into fresh wounds, along with glycerol, decay was stalled for at least 2 years.

Sections from one tree are shown here. C = Control; G = glycerol; TG = *Trichoderma harzianum* mycelial and spore culture with 5 ml of glycerol; TGB = as preceding, plus a culture of bacteria commonly isolated from discolored wood. Note decayed wood in sections C and G. The small holes show where wood chips were taken for isolation of microorganisms. The treatment with the fungus isolate used was not as effective when temperatures were low.


7/73
6/74
C
G
TG
TGB

86. A section from a red maple showing a method used to test the effects of biological agents on the wound response. A wound was inflicted with a chainsaw. Then a metal plate was forced into the center of the wound. The wound on one side of the plate was treated; the other side was left as a control. Because of the way trees compartmentalize wounds, the method is highly applicable.

87. Trees with decayed wood are potential hazards. Trees usually fall as decayed roots break, or trees break at the 2-3-meter trunk level. More dangerous than decayed wood are the vertical cracks. When decayed wood also is associated with cracks on the opposite side of the tree, the tree is a high potential hazard.

88. Hollows in trees are often associated with old, large branch bases. Flush cutting of branches, especially large branches, is a major starting point for large hollows. A flush cut wounds the trunk. Rapid formation of callus follows. The large callus ribs form an oval around the hollows. The U-shaped callus on this tree indicates that the branch was cut too close to the trunk on the upper side.

89. Along with wound dressings, the filling of cavities was considered the mark of a professional tree expert or tree surgeon. The recommendation has been to clean cavities thoroughly before they are filled. "Thoroughly" meant to chip into the healthy wood behind the decayed wood. We now know that the only reason there is a cavity is that after wounding the tree formed strong boundaries about the injured and infected wood. If a cavity is to be filled, the natural boundary should not be broken. Cavities can be filled for aesthetic reasons, but materials that are coarse or abrasive should be avoided. And above all, clean out only the decayed wood that comes out easily. Do not break the boundaries. Boundaries were broken in this large sugar maple. The concrete shows the edge of the original filling, yet dieback extended far beyond it because of the thorough cleaning. Some practices die slowly. Not only are some trees injured severely by extensive internal cleaning beyond the boundary, but in some trees the protective callus is also destroyed. In attempts to help, man has often caused trees many problems. Much of this results from the desire to "play doctor" or "play dentist". Trees are not animals, and should not be treated like animals.

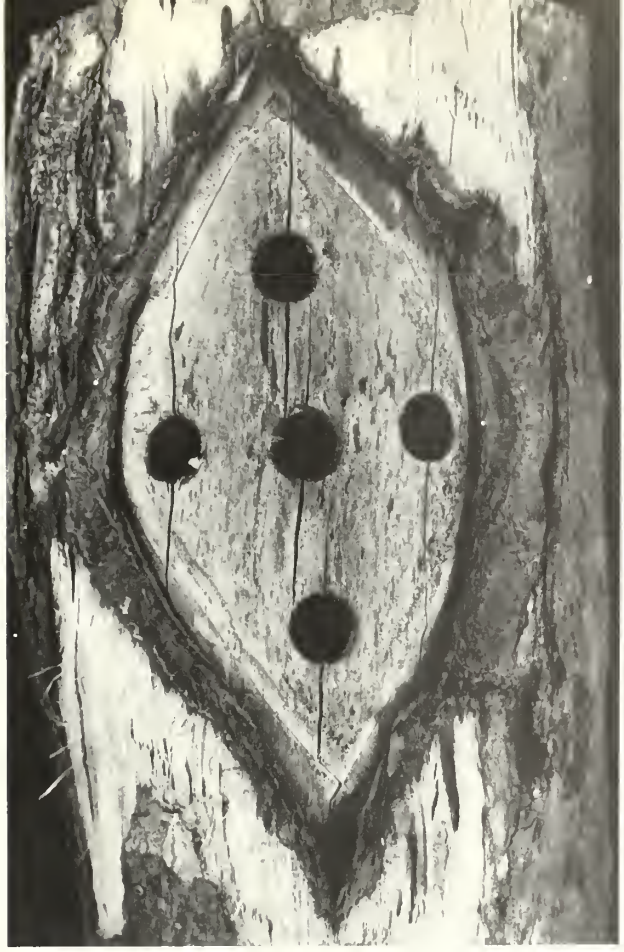
90. Removing dead and dying bark from the margins of fresh wounds can be beneficial to the tree. There is no need to scribe in the form of a vertical ellipse. It is important to cut as shallowly as possible and to round off the margins, especially the top and bottom. More dieback and cracks occur when the top and bottom are strongly pointed.

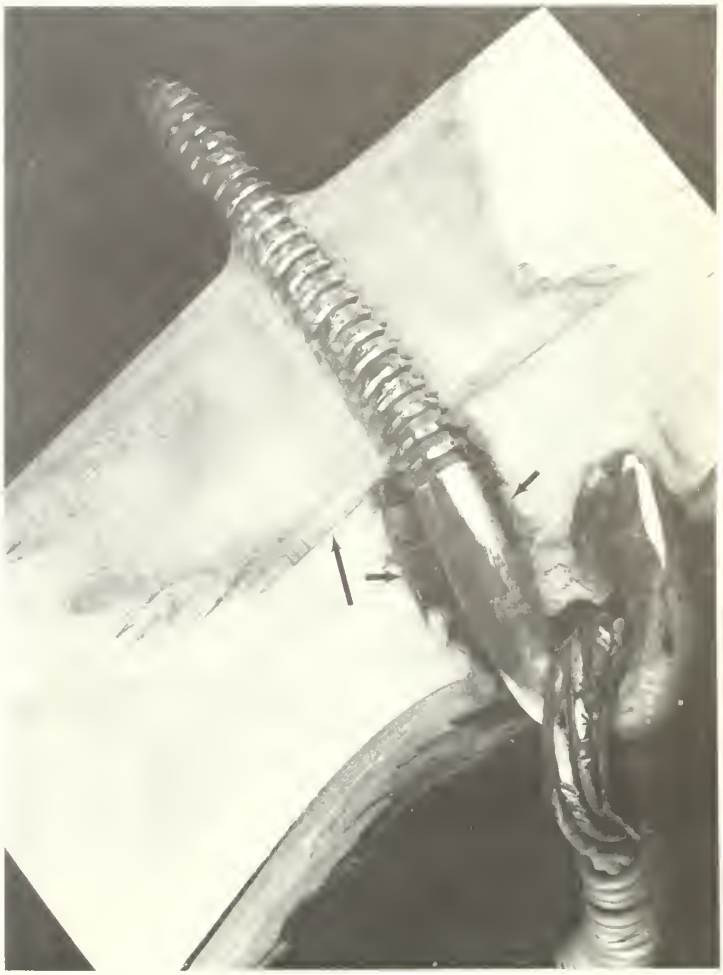
91. Hardware can be placed into trees to help maintain strength. Tubes can be used to drain wetwood fluids, but tubes or holes should not be used to drain water from a cavity. Why the difference? Wetwood is sound wood infected by bacteria. Decayed wood in a cavity is unsound wood. A hole into wetwood will extend the wetwood to the bark. A hole into decayed wood will extend decayed wood to the bark.

Avoid diamond-shaped washers. They cut into the cambium and retard closure, and may increase cambial dieback. Never dead-end hardware into decayed wood. The wood that forms after hardware is inserted does most of the long-term holding. Proper use of hardware can extend greatly the safe and attractive time of a tree.

Discolored wood is on the inner side of this open screw lag in a red oak. The arrow shows the crack that usually forms after insertion of hardware. The open end of the lag is properly set. The new wood will hold for a long time.

92. Screw lag in a maple. Large arrow shows barrier zone that formed after the screw lag was inserted. The top of the lag went into decayed wood, and it fell away in sample preparation. The small arrow shows the cavity that formed as a result of movement of the lag. This type of lag will have a short life, because the new wood that formed after insertion will not hold it.





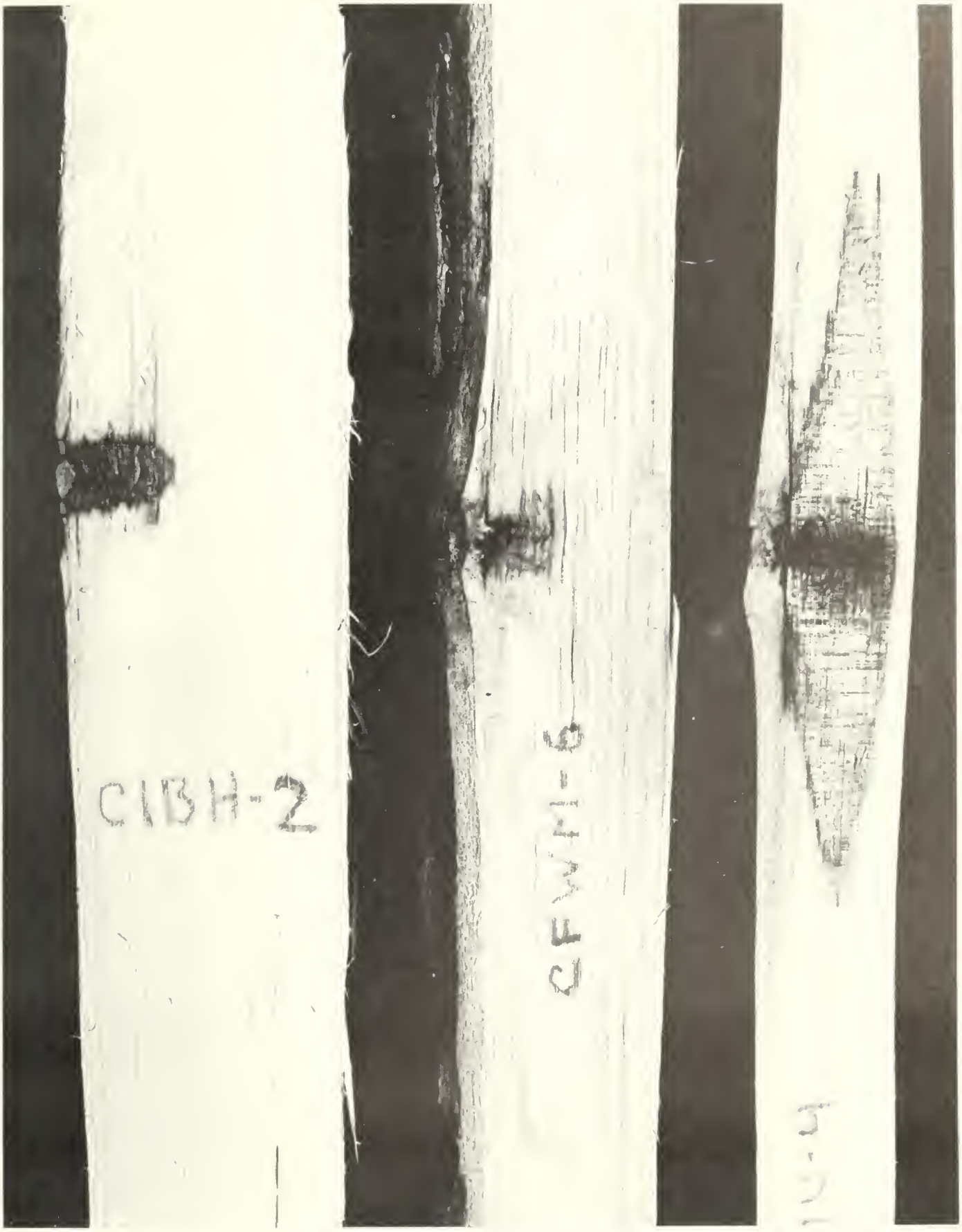
93. Injections and implants are being used for a great number of reasons, from supplying essential elements to adding many types of chemicals to combat insects and fungi. Care must be taken in the treatment so as not to cause more injury to the tree than it had originally. Injections properly done may be beneficial. Proper injections and implants should be as shallow and as small as possible, and at the base of the tree, not into the roots. The root flare was injected repeatedly on this American elm. American elms usually have 12 to 18 clear, healthy growth rings that store energy reserves. The injections and the associated discolored wood have reduced the energy-holding rings to only a few. Discolored wood is dead wood. It is highly doubtful that injections alone could kill a tree, but the combination of repeated wounds and chemicals that cause long columns of discolored wood could weaken a tree and make it an easy target for other invaders.

94. The many experiments conducted with drill holes give information applicable to injection wounds. In elm 132, the injection holes that touched the internal column of discolored wood spread to form large columns. The injection holes that were surrounded by clear healthy wood were walled off to small columns. Also, note the decayed wood in the columns that joined with the already present central column. Injections properly spaced in position on the tree butt, and spaced over time, will not cause serious internal injury. When trees are injected repeatedly over time, the discolored columns associated with the injection wounds begin to coalesce. The volume of wood that would normally hold energy reserves is reduced.

13

95. Most of the transport in a tree occurs in the current growth ring. There is no need to inject beyond this wood. In many cases it is not the wound, but what is put in the wound that causes injury. Several injection methods are now using very small holes—microinjections. These samples show small control holes, in which no materials were injected, in three tree species after 1 year; left to right: shagbark hickory, white oak, and red maple.

Injections in young, smooth-barked trees may result in cracks and blemishes that are considered unattractive. Indeed, attractive bark is a major reason for having ornamental trees. Injection holes, or any type of wound, should never be directly above or below other wounds. Proper injections require a high degree of skill.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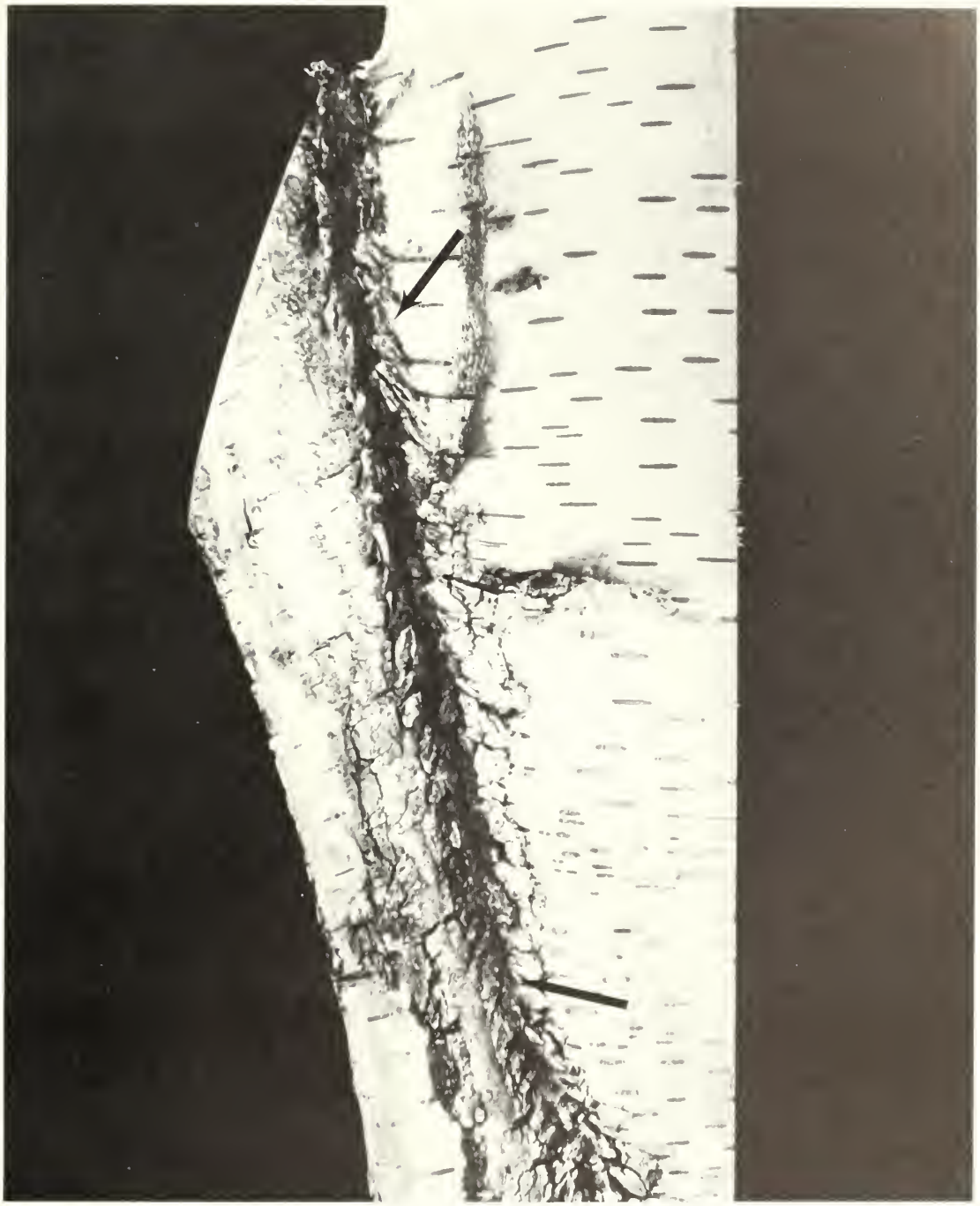
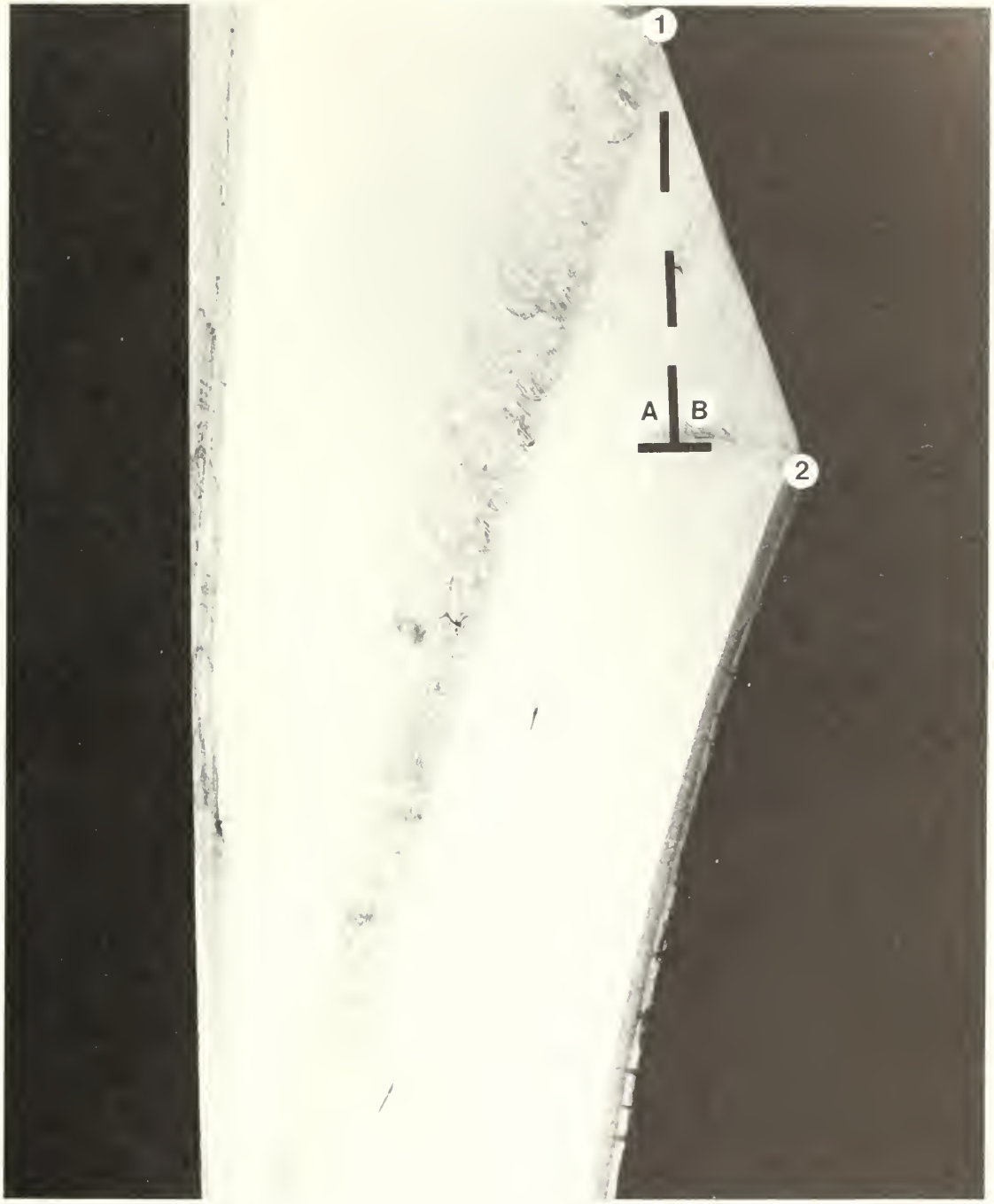
Pruning

Pruning properly done is the best treatment for trees. Pruning improperly done is the worst injury that can be found on trees worldwide. Branches are either cut leaving a long stub, or cut so close to the trunk that a trunk wound results. The close cut, or cut that is flush to the trunk or larger supporting branch, is called a flush cut. Such cuts have been recommended for hundreds of years. Why flush cuts? A flush cut injures the larger supporting branch or trunk. When the larger stem is injured, it begins to form a callus. The formation of callus has been considered a sign of "healing". Therefore, the idea was, to promote healing, cut branches flush. The more flush, the larger the callus, therefore the better the "healing". We now know that trees do not replace injured wood; callus is formed by the new growth rings that continue to grow after the pruning cut. Large branches cut flush will form large oval callus rings. When the center decays away, a cavity is formed. Large flush cuts are major causes of cavities. Here are some photos that show proper and improper pruning, and the internal results.

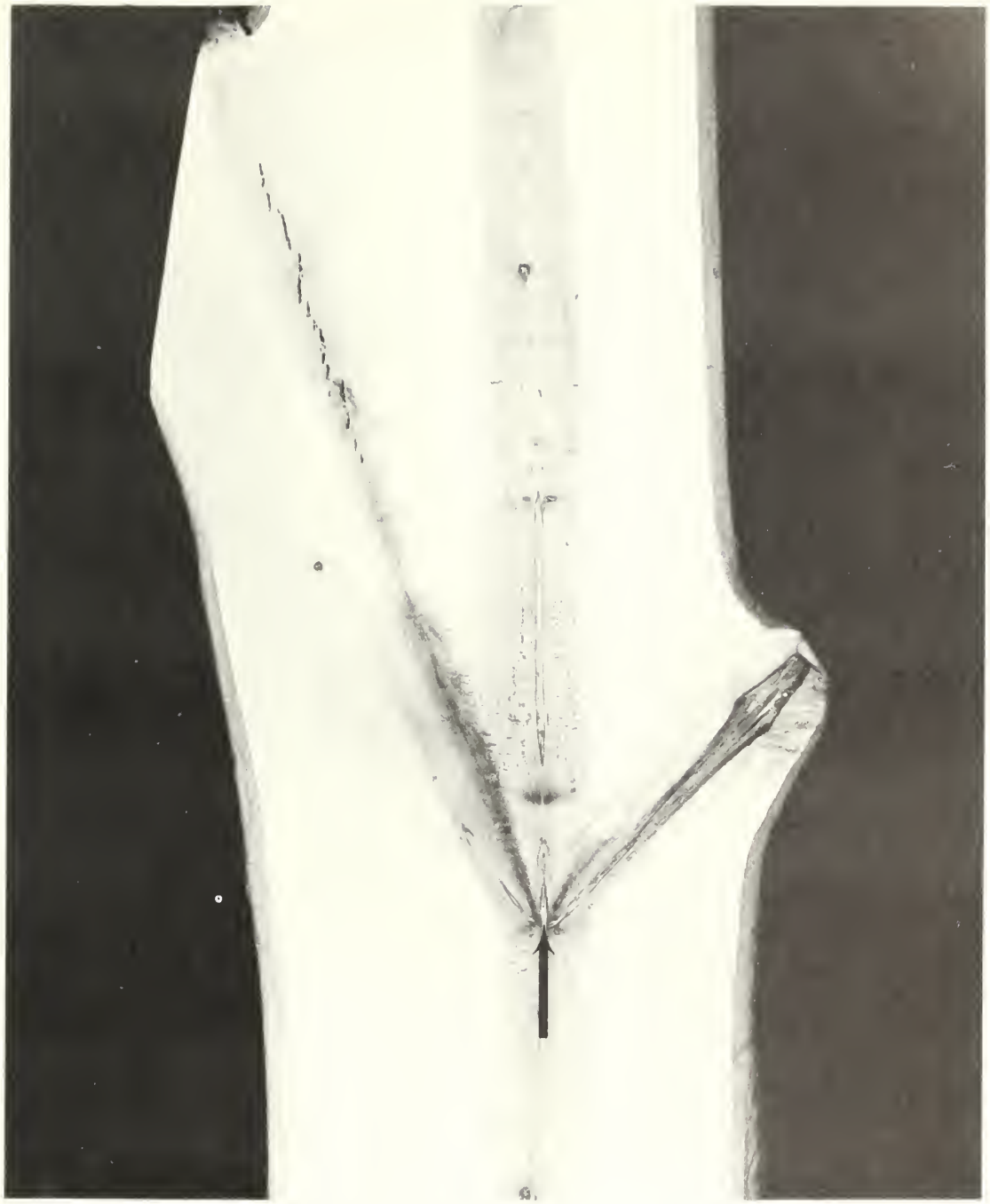
96. The branch bark ridge (BBR) (arrows) is very pronounced on this paper birch sample. The cut is at the proper angle. The BBR forms as the enlarging branch pushes against the enlarging stem. The branch enlarges as an expanding cylinder, and so does the stem. But, the two expanding cylinders are at an angle, and the meeting of the two constantly expanding cylinders produces the BBR at the crotch of the branch. The raised bark is carried on the bark as a ridge. The lowest point of the BBR shows where the branch started as a bud.



97. Dissection of the birch sample shown in the previous figure shows the inner hard tissues that separated the developing branch from the expanding stem. Target 1 shows that the trunk has not been wounded. Target 2 is the part where the expanding circle of the trunk meets the expanding circle of the branch. Tissues below target 2 are trunk tissues. If a straight line were drawn as shown, from target 1 downward, Angle A to the BBR equals Angle B to the proper angle of cut. When in doubt about target 2, the straight line can be "drawn" in your mind on the outside of the stem, and the proper angle of cut determined very easily.


1
A
B
2

98. Properly cut living branch on a red maple. Note that the hard inner tissues that separate the branches from the stem start at the point where the buds were set on the end of the twig (arrow). The hard inner tissues that are shown as the BBR on the outside separate the two branches from the trunk. The small branch on the right died, and it was shed. Trees do not cast off branches; the trees wall off the branch, decay spreads downward to the branch base, and the weakened branch falls away. All properly shed branches will have a small pocket of walled-off decayed wood at the branch base. The decay seldom spreads; it is walled off in the branch compartment.



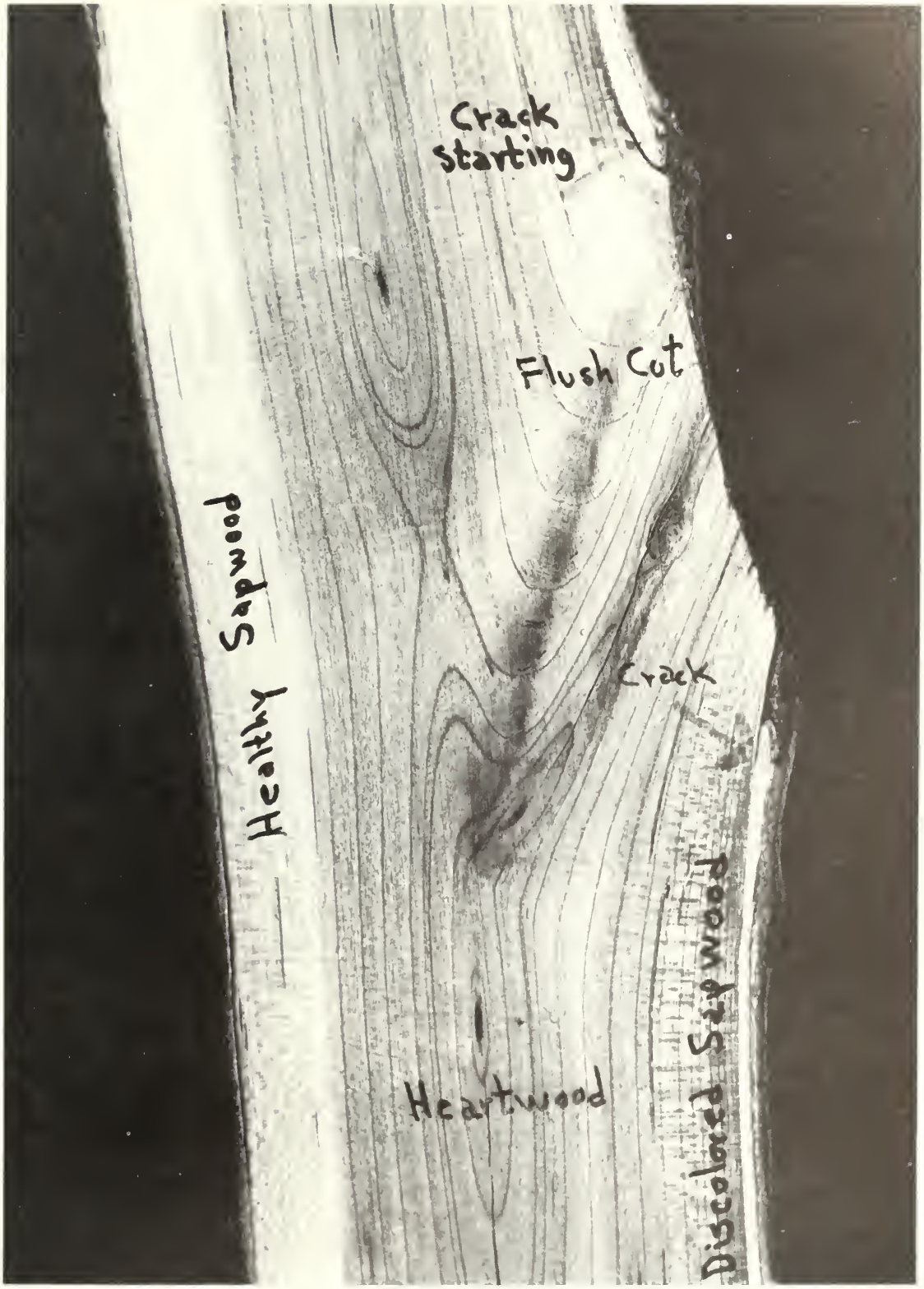
99. Dissections of a red maple stem showing a dead branch and its union with the living trunk. As branches wane and die, many microorganisms begin to infect the dying and dead tissues. Decay-causing fungi usually infect and begin to spread downward to the branch base, or the branch collar. The branch collar is the swollen basal tissue—trunk tissue. As the branch dies and as microorganisms spread downward, the tree begins to form a boundary of chemicals at the position where the last area of branch tissue is enveloped by trunk tissue. In hardwoods, the boundary contains a high concentration of phenol-based materials, many of which have been oxidized, and thus act to inhibit the spread of many microorganisms, especially the decay-causing fungi. When pruning dead and dying branches, great care must be taken not to remove the protective boundary zone. Do not leave a stub. Do not flush cut. Cut as shown in the figure. Do not remove the living ring of wood that surrounds dead branches. Note the well-compartmentalized pocket of decayed wood associated with the small lower dead branch core wood. The inner BBR is also shown.

No
Yes
No

100. A yellow birch pruned in January, 1981, and dissected in July, 1981. Upper branch properly pruned, lower branch improperly pruned.

101. Improper cut on left, and proper cut on right, of a white pine after 1 year.

102. One growing season after improper cutting of a living branch on a black cherry. Note discolored band of sapwood on flush cut side. Only a thin band of sapwood is above and below the cut. The discolored sapwood reduces the volume of wood that stores energy reserves. The single growth ring of sound sapwood may easily crack or split from sudden cold or sudden heat—"frost cracks" or "sunscald". Insects often infest the thin band of tissue. Canker-causing fungi often infect the weakened tissues around such cuts. Cracks may also form as Wall 4 forms. All because of a flush cut!


Crack
Starting
Flush Cut
Healthy Sapwood
Crack
Heartwood
Discolored Sapwood

103. Proper cut of a red oak branch after 50 years. Closure was complete. The brown rot that was in the branch at the time of pruning was still walled off within the branch.

104. Improper cut of a red oak branch after 30 years. Closure looked complete, but the crack was still open, and made conditions perfect for the decay-causing fungi. Decay was advanced in the wood present at the time of the harsh flush cut. Insects infested the dying tissues surrounding the cut, in spite of the coating of wound dressing on the surface of the cut. Such cuts cause serious injury.

105. Summary of proper and improper pruning: The three samples are rubber models all made from the same section of paper birch. The model at right shows a living branch cut too long (left), and a dead branch cut too long (right). The center model shows proper pruning of a living and dead branch. The model on the left shows improper (too close) pruning: live branch (left): dead branch (right).

106. When it is necessary to cut off the leader of a tree and have a branch develop as a new leader, the old leader should not be cut flat across the stem. This type of "flat-top" cut will start decay rapidly. The proper cut is on the left; the flat-top cut is on the right. Both red maple trees were the same age. Note the complete ring of callus on the left sample. When a top cut must be made, start on the inner side of the branch bark ridge, opposite where you start when removing a branch. The cut should be slanted at approximately the angle of the branch that will be the new leader, which will also be fairly close to the angle of the branch bark ridge.

107. Dissection of the red maple samples shown in the previous figure; proper top cut on left, improper cut on right, after 3 years. When a top cut is made, it causes serious injury no matter how it is done. But the degree of injury can be greatly reduced by starting on the inner side of the BBR, and slanting the cut approximately at the angle of the BBR. The word "approximately" is used here because it is difficult to determine the exact angle of cut due to the bends in the branches. But flat-top cuts should never be made. Why? The stub of wood that remains will be dying wood, and microorganisms spread most rapidly in dying wood. The stub will be alive, but defenseless, just like a branch stub. The tree walls off the cut where the end of the original cut should be made. The angle of the proper cut was determined from dissections of flat-top cuts, as shown on the right. Note the large amount of decayed wood in the right sample. Flat-top cuts are causes of serious injury to orchard trees, especially species of *Prunus*. Ornamental cherry varieties are also very sensitive to flat-top cuts.

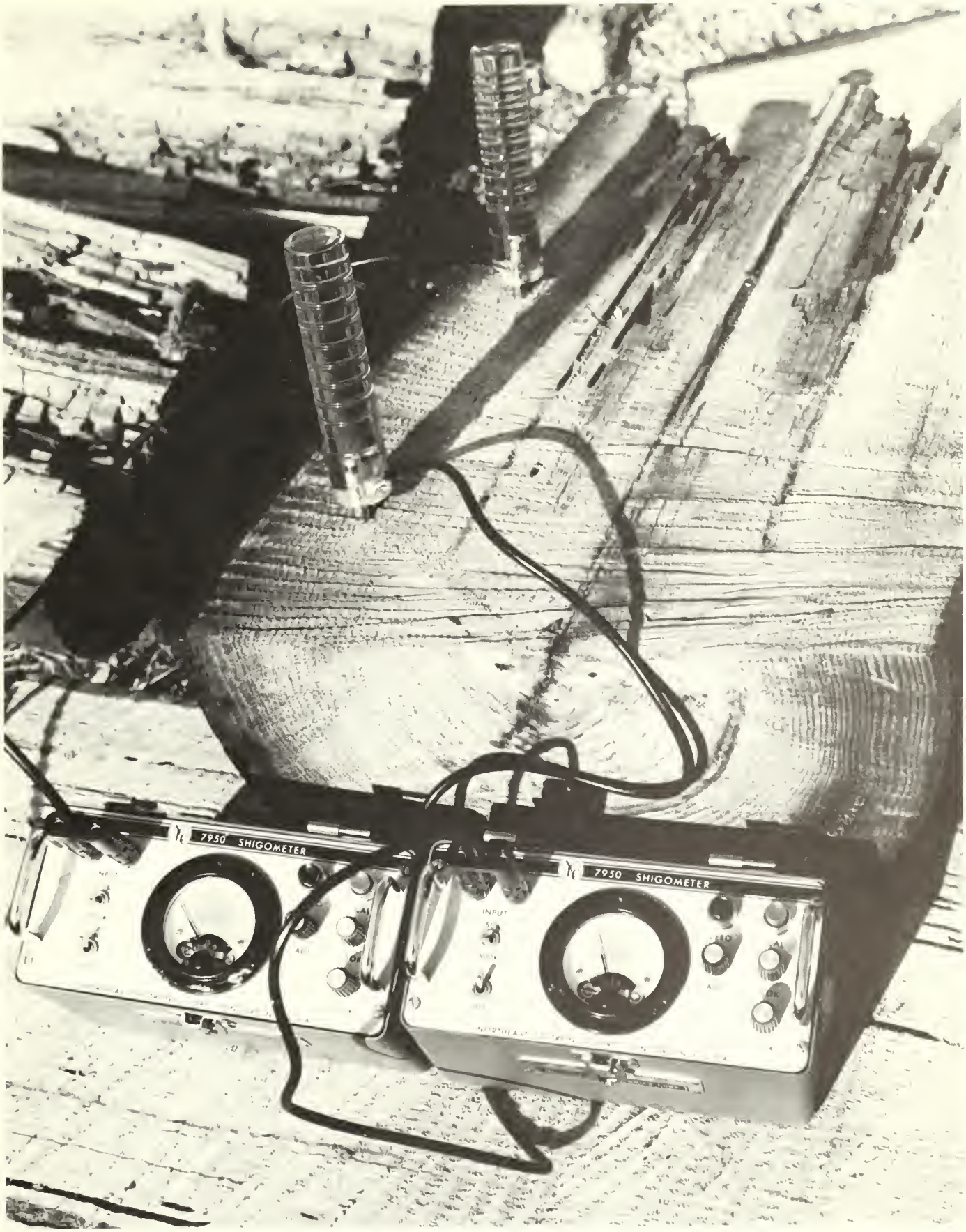
Topping cuts should not have too steep an angle. A steep angle cut will lead to decay above and below the cut. Improper topping cuts can lead to limb drop, as the new leader grows larger and as the decay in the old trunk develops downward.

108. Many defects in wood products have their origin in the living tree. After a branch or root dies, or the tree is wounded, the tree responds by setting boundaries to resist the spread of infections. The boundaries are often the sites of cracks in wood products. Also, the injury-altered wood within the boundaries is often the first wood to be attacked by other microorganisms when it is made into a product. Insects—ants, termites—also infest first the injury-altered wood. In many cases the wood is really not defective when it goes from the tree to the wood product, but it will not last long. The many large stubs in this pole were the start of problems about 15 years after the pole was set. The wood that was altered when the branch died began to decay. The decay did not spread into the heartwood or outward to the wood *that formed after the branch died.* The pattern of decay was not determined by where the preservative penetrated. Cracks started from the internal decayed wood and spread outward. (Checks start from the outside and move inward.) Ants infested the decayed wood through the cracks. Woodpeckers bored many holes in the pole to eat the ants. The poles had to be replaced.

109. Dissected view of pole sample shown in previous figure. Note the column of decayed wood associated with the branch wood.

110. New electrical tools have been developed that now make it possible to detect decayed wood in living trees and in wood products. The meters register, in ohms, the resistance to a pulsed current that is generated by the meter and passed through the wood through a variety of electrodes. A skilled operator who understands wood and trees, and CODIT, can use the pattern of electrical readings to help determine the internal condition of the wood.

For experimental purposes, the meters are being used with double-needle, noninsulated electrodes to measure the resistance of the wood directly below an obvious column of brown rotted wood (above) and wood distant from the brown rotted wood (below). The meter on the left shows 20 Kohm for the upper electrode; the meter on the right shows 140 Kohms for the lower electrode. Note also how abruptly the brown rot ends.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The expanded concept and the model are used to
many other tree problems. Defects are major causes of low quality in trees. Use of the information in the guide can help foresters and urban foresters to grow healthier, higher quality trees.

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Keywords: Compartmentalization, discolored and decayed wood, CODIT, pruning, tree care.

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